JOURNAL

OF THE

INSTITUTION OF ELECTRICAL ENGINEERS,

ORIGINALLY

THE SOCIETY OF TELEGRAPH ENGINEERS.

FOUNDED 1871. INCORPORATED 1883.

EDITED BY P. F. ROWELL, SECRETARY.

INDEX TO
VOLS. 31 TO 47, 1901–1911.

E. AND F. N. SPON, LIMITED, 57, HAYMARKET, LONDON, S.W.

SPON AND CHAMBERLAIN, 123, LIBERTY STREET, NEW YORK.

1912

v. 47

KEY SHOWING PAGES CONTAINED IN EACH PART OF THE JOURNAL.

VOLUME AND YEAR.	PAGES.	PART NO.	VOLUME AND YEAR.	PAGES.	PART NO.
31, 1901–2	1–244	153	**38,** 1906–7	453–644	183
	245–442	154			
	443–672	155	**39,** 1907	1–266	184
	673–970	156		267–500	185
	971–1218	157		501–794	186
	1219–1371	158			
			40, 1907–8	1–234	187
32, 1902–3	1–276	159		235–452	188
	277–518	160		453–650	189
	519–646	161			
	647–924	162	**41,** 1908	1–224	190
	925–1161	163		225–532	191
				533–872	192
33, 1903–4	1–98	164			
	99–360	165	**42,** 1908–9	1–230	193
	361–618	166		231–470	194
	619–892	167		471–710	195
	893–1028	168			
	1029–1219	169	**43,** 1909	1–232	196
				233–564	197
34, 1904–5	1–254	170		565–828	198
	255–508	171			
	509–780	172	**44,** 1909–10	1–278	199
				279–534	200
35, 1905	1–224	173		535–822	201
	225–444	174			
	445–588	175	**45,** 1910	1–292	202
				293–506	203
36, 1905–6	1–228	176		507–774	204
	229–474	177			
	475–654	178	**46,** 1910–11	1–232	205
				233–506	206
37, 1906	1–160	179		507–760	207
	161–444	180			
			47, 1911	1–310	208
38, 1906–7	1–208	181		311–606	209
	209–452	182		607–868	210

NOTE.—Copies of the General Index to Volumes 1 to 10 (years 1872–81), 11 to 20 (years 1882–91), and 21 to 30 (years 1892–1901), are still obtainable from the publishers, or from the offices of the Institution, price 2s. 6d. per copy.

INDEX

TO VOLUMES 31 TO 47, 1901-1911.

EXPLANATION OF ABBREVIATIONS.

(P) indicates a reference to the author and title of a paper.

(D) indicates a reference to remarks made in a discussion upon a paper, the title of which is quoted.

(*Ref*) indicates a reference to publication elsewhere.

Note.—The number of the volume is in clarendon type, and the page is in roman.

A

B

D.

E.

F.

G.

H.

I.

L.

MISCELLANEOUS.

General.

N.

O.

P.

POWER STATIONS.

Costs, Tariffs, Policy, and Finance.

Principles underlying the profitable sale of electricity. A. WRIGHT. **31,** 441.
Supply of electricity in bulk. H. A. EARLE. **31,** 884.
Influence of sub-station equipment and transmission line on the cost of electricity supply. A. STEWART. **31,** 1122.
Electrical legislation and finance. H. W. HANDCOCK. (*Ref*) **31,** 1371.
Motive power supply from central stations. R. A. CHATTOCK. **32,** 621.
Electricity supply for small towns and villages. A. B. MOUNTAIN. **32,** 1017.
Station notes. C. TURNBULL. (*Ref*) **32,** 1161.
Should electric supply undertakings advance motors on the hire or hire-purchase systems? S. E. BRITTON. (*Ref*) **33,** 1218.
Methods of charging for electrical energy. E. H. CRAPPER. (*Ref*) **33,** 1219.
Standby charges and motor-load development. A. M. TAYLOR. **35,** 227.
Economic considerations in the employment of storage batteries. J. R. SALTER. **37,** 228.
Cost of electricity per unit from private electrical plants. W. HARTNELL. (*Ref*) **37,** 443.
Stores and cost-keeping for electricity supply undertakings. D. DENHOLM. **39,** 164.
The pay-sheet. R. B. MACCALL. **39,** 187.
Depreciation. R. HAMMOND. **39,** 270.
Central station supply economics. A. M. TAYLOR. **39,** 364.
Cost of electrical power for industrial purposes. J. F. C. SNELL. **40,** 288.
Commercial aspect of electric power supply. W. B. WOODHOUSE. **40,** 432.
Electricity supply prospects and charges as affected by metallic filament lamps and electric heating. H. W. HANDCOCK and A. H. DYKES. **41,** 232.
Domestic electricity supply as affected by tariffs. W. R. COOPER. **42,** 26.
Plans and records for electrical distribution systems. J. W. BEAUCHAMP. **42,** 575.
Economics of medium-sized power stations. A. J. J. PFEIFFER. **43,** 567.
Isolated electrical plants. R. C. PLOWMAN. **45,** 649.
Power company's testing department. E. FAWSSETT. **47,** 752.

Fuel, Boilers, and Feed-water.

Feed-water for boilers. C. J. WELLS. (*Ref*) **31,** 1370.
Steam boilers. C. E. STROMEYER. (*Ref*) **31,** 1370.
Electricity from refuse. W. F. GOODRICH. (*Ref*) **32,** 1161.
Coal consumption in central stations. A. S. GILES. (*Ref*) **33,** 1219.
Fuel economy in steam-power plants. W. H. BOOTH and J. B. C. KERSHAW. **34,** 329.
Condensing arrangements in central stations. J. D. BAILLIE. **34,** 491.
Softening and purification of water for steam raising. L. J. LE CLAIR. (*Ref*) **35,** 587.
Power gas. F. H. BOWMAN. (*Ref*) **35,** 587.
Coal testing. J. HOLLIDAY. (*Ref*) **37,** 443.
Destructors and their by-products. F. L. WATSON. (*Ref*) **37,** 443.
Fuel economy. H. B. MAXWELL. (*Ref*) **39,** 792.
Examination of water by electrical methods. W. P. DIGBY. **45,** 541.

Q.

R.

S.

U.

V.

Y.

Z.

The Gresham Press
UNWIN BROTHERS, LIMITED
WOKING AND LONDON

JOURNAL

OF

The Institution of Electrical Engineers.

Founded 1871. *Incorporated* 1883.

VOL. 47. 1911. NO. 208.

Proceedings of the Five Hundred and Nineteenth Ordinary General Meeting of the Institution of Electrical Engineers, held on Thursday, March 23, 1911—Mr. S. Z. DE FERRANTI, President, in the chair.

The Minutes of the Ordinary General Meeting held on March 9, 1911, were taken as read and confirmed.

Messrs. S. W. Melsom and E. H. Rayner were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected :—

ELECTIONS.

As Members.

Stuart Strickland Moore Ede.
George Marshall Harriss.
Philip Lyle Riviere.

As Associate Members.

Hubert Reginald Baldwin.
John Burbridge.
Robert William Clark.
Augustus Charles Coward.
George Frederick Findley.
Harold George Jeken.
Edmond Weston Kay.
William Cecil Kirwan.
Frederick Ernest Mitton.
William Owen Pepper.
William Griegson Pickvance.
Henry Keppel Reed.
Percy Morris Sanger.
Lewis Mair Silver.
John Henry Thomas.
Ernest Owen Turner.
William Francis White.
James Laing Wilson.

As Students.

Edgar Philip Ashworth.
Arthur James E. Bates.
Sydney Burns.
Wilfrid George A. Corben.
Leonard George Dimmer.
William Donald Douglas.
George Harry Elsden.
William Stanley Flight.
Ernest Alexander Gordon.
William Soutar Harvey.
Walter Ernest Hatfield.
Henry James Henwood.
Gordon Alfred Hollings.
Gordon Hughes.
Edgar Wilfred King.
Reginald Levy.
Lloyd Lewis.
Charles William Marshall.
James Meikle.
Mohammad Abd El Latif Moharram.
Louis St. Vincent Norris.
David Victor Oppenheim.
Apabhai Chaturbhai Patel.
Rupert Leslie Printz.
Edward Loyd M. Protheroe.
Harold Walter Puttick.
Antonio Rodrigues Teixeira.
Johannes Adrianus Van Tilburg.
Frederic John Tompson.
Rudolph Wenning.

The following paper, "Electricity Meters, with Notes on Meter Testing," by H. A. Ratcliff and A. E. Moore, Associate Members (see page 3), was read and discussed.

ELECTRICITY METERS, WITH NOTES ON METER TESTING.

By H. A. RATCLIFF and A. E. MOORE, Associate Members.

(*Paper received February* 17, 1911; *read before* THE INSTITUTION *March* 23, 1911; *and before the* MANCHESTER LOCAL SECTION *March* 21, 1911.)

SUMMARY OF CONTENTS.

Under the title of "Electricity Meters" only such meters are to be understood as are used for the measurement of electrical energy. It is unfortunately a fact that these meters are frequently misnamed; for instance, it is a common mistake to speak of an electricity meter as a "wattmeter," thus making confusion between the units of power and energy. Electricity meters will therefore be considered as watt-time or Joule meters.

There can be no doubt as to the importance of the subject, although meters are frequently a neglected item of an electricity supply department's equipment. As a rule, they are rarely overhauled, and on some systems never even tested; the result being that although such importance is attached to the last half of 1 per cent. efficiency

in the stations, at least 5 per cent. may be lost in distribution, due to defective meters. Consequently it pays to test meters properly before fixing, and also at regular intervals afterwards.

Most of the well-known makes of meters, if properly adjusted and carefully fixed, may be relied upon for about five years; but after that time it certainly pays to have them brought in for thorough overhauling and recalibration. Old meters, after careful repairing and recalibrating, are frequently better than when new, and the cost of the work, if carried out in a properly equipped meter department, is comparatively slight.

In the case of large power consumers, where the conditions of supply justify a low rate per unit being charged, an error of 2 or 3 per cent. on the meter reading may make all the difference between a profit and a loss. Extreme accuracy is therefore essential, and it is always advisable in such cases to install duplicate meters, as greater accuracy can then be obtained, and a further advantage is that it is always possible to remove one meter for testing, when necessary, without having to leave the supply unmetered, or having to fix a temporary meter.

CLASSIFICATION OF METERS.

Electricity meters may be grouped into three main classes :—

1. Meters suitable for direct current only.
2. Meters suitable for alternating current only.
3. Meters suitable for direct and alternating current.

Each of these groups has its sub-divisions, of which particulars are given later.

Direct-current Meters.

Direct-current meters may be either of the ampere-hour or the watt-hour type. Most ampere-hour and a few of the watt-hour meters belong to the first class named above. The remaining types of direct-current watt-hour meters belong to the third class, and may, as a rule, with occasional slight modifications, be used for measuring the energy in alternating-current circuits.

Ampere-hour versus *Watt-hour Meters.*—Various claims are put forward on behalf of both ampere-hour meters and watt-hour meters. A brief comparison of the advantages and disadvantages of these types may therefore not be out of place.

The watt-hour type of meter is, if correct, a true energy meter, *i.e.*, it measures correctly the electrical energy in a circuit, independently of variation (within reasonable limits) in any of the three factors (volts, amperes, hours) involved in the quantity measured.

The authors are therefore of the opinion that this is the only type of meter which should be legally recognised as a measurer of electrical energy, although, at the same time, they quite realise the advantages of ampere-hour meters.

The ampere-hour type of meter can only measure energy correctly on the assumption that one of the factors—viz., voltage—is a constant, and the authors hope that the discussion may throw some light on the justification for this assumption. In addition to measuring the true energy in a circuit, watt-hour meters also possess the advantage that they may be made to start with extremely small currents, owing to the fact that they may be compounded to correct for friction losses, etc.; whereas in most cases it would not be either convenient or legitimate so to compound an ampere-hour meter.

One of the principal arguments raised in favour of ampere-hour meters as against watt-hour meters is the supposed enormous shunt or pressure circuit losses. On investigation it will be found that these losses have been greatly exaggerated, and, as a matter of fact, are frequently exceeded by losses of much greater importance where ampere-hour meters are used. The pressure circuit loss in a watt-hour meter is very small, and, moreover, has a load factor of 100 per cent., so that the revenue loss to the station has to be reckoned on the lowest possible basis, and will, therefore, in any case, hardly exceed ¼d. per unit. Now, ampere-hour meters also have their losses, although the fact is frequently unsuspected, and, in this case, the conditions are far more unfavourable. Presumably every station engineer endeavours to maintain a fairly reliable supply pressure, and with this end in view usually runs with a pressure on the distributors rather over, than under, the declared value, probably to the extent of 2 per cent. at least. Meters of the ampere-hour type, however, must be calibrated for the declared pressure, and it follows that 2 per cent. or more of the revenue is lost, and the greatest loss is naturally at the time of peak load, when the cost per unit is at its maximum.

As an example, take the case of a 10-ampere 200-volt meter; the shunt losses in one of the watt-hour type would not exceed 4 watts, and at ¼d. per unit this amounts to 8¾d. per annum, the corresponding loss to the station with an ampere-hour meter, assuming an average load equal to a half of full load for 1½ hours per day, would be equal to 2 per cent. on, say, 247 units, which, at 3½d. per unit, is equal to 3s. 2d. per annum. The difference between these two amounts is sufficient to allow for a smaller number of units used, lower percentage excess pressure, and higher running costs, and yet show an advantage in favour of the watt-hour meter. If the station engineer runs below the declared pressure, then, of course, the conditions are reversed.

Although it has been stated that watt-hour meters are the better type as regards the correctness of their measurements, it must nevertheless be admitted that ampere-hour meters possess many advantages and, in some cases, are undoubtedly more suitable for the particular conditions obtaining. They are certainly much simpler to test and install than watt-hour meters, and, as a rule, easier to repair and less liable to get out of order; the price is also much below that of the watt-hour type.

In England it has been the more frequent practice to use ampere-

hour meters, whereas on the Continent watt-hour meters were used exclusively up to two or three years ago, and this is still the standard practice in America.

Ampere-hour meters of a particular type were introduced on the Continent a few years ago, but with indifferent success, probably owing to the type of meter used. Quite recently, however, the mercury type of meter has been tried, and so far presumably with successful results.

Types of Ampere-hour Meters.

The three main types are: the mercury motor, commutator motor, and the electrolytic.

Mercury Motor Types.—The mercury motor meter may, so far as English practice is concerned, be justly regarded as the survival of the fittest; probably 80 per cent. of the direct-current meters used in this country belong to this class, and represent the output of two firms that have had extensive experience with this type of meter.

These meters are thoroughly strong and robust in construction, the workmanship is rather rough, but sufficiently finished where essential.

The accuracy is reasonably good, and they are fairly easy to adjust and calibrate, and, as might be expected from their construction, repair work is comparatively simple. The greatest objections to this type of meter are:—

The impossibility of maintaining a sufficiently high driving torque as the current-carrying capacity is reduced (a very important point now that the average size of meter is falling); this, of course, is owing to the fact that the factor represented by the magnetic field is a constant, and to the impossibility of increasing the ampere-turns as the current is reduced.

Troubles Due to the Use of Mercury.—Mercury troubles are necessarily an inherent defect of the type, and vary to a great extent according to the size of the meter, the nature of the load, and local conditions generally.

The most frequent forms of mercury trouble are amalgamation, and what appears to be a gradual disintegration or oxidation of the mercury.

Amalgamation is, as a rule, most pronounced in the armatures, and it appears to be only a matter of time before even the best protected armature is attacked; but the action can be prevented for several years by careful platinising and enamelling. The old covered armatures made by one firm several years ago have been found in good condition after nine years' use.

The disintegration trouble when very bad results in the complete conversion of the mercury to a grey powder. This effect is only properly observable in shunted meters, as otherwise the circuit would be broken, and the meter badly damaged before the state of complete disintegration had been attained.

Meters in which a comparatively large current is taken through the mercury chamber (say 50 to 100 amperes) are subject to another peculiar effect which appears to be partly, if not entirely, of an electrolytic nature, the copper of the positive electrode or anode being taken into solution and deposited at the negative electrode or cathode.

Mercury meters have undergone considerable modification in detail during the last year or two, but all are based more or less on the original "Hookham" models.

A comparatively new meter of this class is constructed on lines quite contrary to the experience of the older manufacturers. The more startling innovations are: an extremely small air-gap, the use of an amalgamated armature, and the absence of any compensation for mercury friction. This design is only permissible on the assumption that the copper and mercury used are both chemically pure, and whether this condition can be satisfied on a practical and commercial scale, is open to considerable doubt; but even if pure when first put into the meters, the mercury must sooner or later become impure when in contact with an atmosphere such as that of Manchester.

It was at one time customary to make mercury meters up to a current capacity of 100 amperes with the whole of the current passing through the bath; in fact, one of the authors has had experience with a total current type of meter intended to carry 500 amperes, but it is now usual to shunt all sizes above 50 amperes, and some makers shunt above 10 amperes or even less.

Shunting has the additional advantage of reducing the somewhat considerable temperature error; but errors on fluctuating loads may be introduced unless the inductances of the shunt and bath circuits are balanced.

Commutator Type Ampere-hour Meters.—This type of meter is of Continental origin, and has been on the market for about twelve years; its defects are, however, gradually becoming recognised, and it is therefore probable that it may eventually be superseded by a superior type.

Apparently introduced to meet the demand for an inexpensive meter, in place of the costly watt-hour type, it has created a considerable demand for ampere-hour meters, and, as a result, the previously banned mercury meters now have an extensive sale on the Continent.

This class includes all meters in which a wound armature connected in parallel with a low resistance shunt rotates in the field of a permanent magnet.

The only advantage of this type is that the torque may be maintained practically constant independently of the rated current-carrying capacity, as owing to the extremely small current taken by the armatures, and the use of a shunt, the potential difference on the armature terminals may be adjusted to any desired value (within the limits of permissible voltage drop) irrespective of the current rating.

The armatures are, as a rule, flat, but in one or two cases cylindrical, and, with about one exception, are all wound on metal formers; so that

they are magnetically damped by the eddy currents generated in the disc or cylinders on which the coils are wound.

The theory of the undamped meter is based on the law of a perfect motor; but as armature resistance and friction are not eliminated, the curve of accuracy is bound to fall rapidly on the low loads. The speed of this type is also exceptionally high.

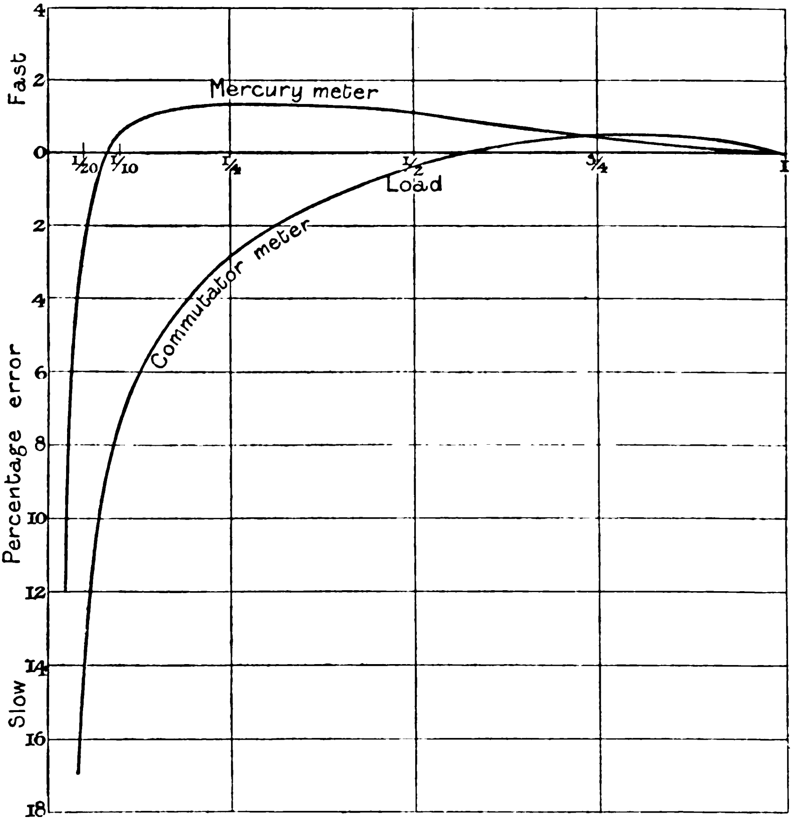


FIG. 1

The damped type of meter has a more moderate speed than the undamped type, but requires a higher working voltage across the armature; it is also more susceptible to changes in brush position and contact resistance, for which the only cure is increased voltage drop. The automatic brush-rocking devices, intended to overcome these troubles, have only been partly successful, and, at the same time, are open to the objections that they complicate the construction, reduce the reliability, and increase the price.

The usual drop in the shunt is from 1 to 1·5 volts at full load.

The general construction is, as a rule, rather flimsy.

The torque may be very high, but is, of course, obtained at the expense of voltage drop.

The two curves in Fig. 1 have been plotted from the mean results of a large number of tests on different makes of meters, and are characteristic of the mercury motor and commutator types respectively.

Electrolytic Meters.

These meters necessarily belong to the ampere-hour variety (claims have recently been made for a watt-hour electrolytic meter), but otherwise constitute a distinct class.

In the opinion of the authors, the disadvantages of electrolytic meters so completely outweigh the advantages, that they can hardly be regarded as cheap, even at the present low prices.

Low price is probably the chief advantage claimed on behalf of electrolytic meters; but first cost is only of secondary importance, and it is essential that full consideration should be given to the questions of life, and the possibilities of easy repair and recalibration. A well-made motor meter should be equal to, if not better than new, when repaired, etc., after five years' work, and, moreover, the cost of putting it into good condition is trifling, but the same can hardly be said for meters of the electrolytic type.

It has been stated that these meters are dead accurate on all loads, even down to 1 per cent. or less of full load; but the experience of the authors does not substantiate this, since it has been found by direct comparison that reliable motor meters are more accurate than electrolytic meters on the higher loads, and quite as accurate on the very low loads.

Admitting the low price to be an advantage, the following are a few of the disadvantages of electrolytic meters generally :—

(*a*) Delicate and unmechanical construction.
(*b*) Impossibility of reasonable repair.
(*c*) Difficulty and expense of testing under working conditions.
(*d*) High voltage drop.
(*e*) Difficulty of correct reading.
(*f*) Difficulty of correct resetting.
(*g*) Destruction of record by resetting.
(*h*) No check on "set-up" or "removal" readings.
(*i*) Many are dirty and messy in operation.
(*j*) Life certain to be short, and cost of renewals probably 50 per cent. of initial cost of meter.

In the authors' opinion, the destruction of the record is a very serious matter, and the registering device in all meters should be a continuous one. Where dials are provided the registration must of necessity pass through zero once in 10,000 or more units, but there is

never any doubt as to the number of units used if the correct sequence of figures is observed from the periodic readings.

The only electrolytic meters that have come into extensive use are the "Bastian" and the "Reason."

The former is necessarily a total current meter, and is of the water decomposition type. It has an abnormal voltage drop (about 3 volts at full load), and requires periodic refilling. If working for prolonged periods at loads approaching the rated maximum, errors may be introduced due to evaporation. Correct reading of the scale is difficult after the meter has been in use for any length of time, and practically impossible when the current is passing through the meter.

The "Reason" meter is a shunted one, and has a drop of 1 volt at full load. It belongs to the metal deposition class, and requires no renewal of electrolyte or electrodes; the metal deposited is mercury, and can, by suitable tipping arrangements, be used over and over again, presumably without any chemical changes taking place in the solution.

The meter is very fragile, and by no means easy to re-set properly. Repairs are expensive, and should they become a frequent necessity, will be fatal to the success of the meter; the present design, in the authors' opinion, suffers from the disadvantage that in order to fix the meter it is necessary for the fixer to expose the delicate interior, and, moreover, work with his screwdriver in immediate proximity to a slender glass tube.

It is the authors' opinion that all meters should be so constructed that they may be both read and sealed (with the exception of the terminals box) by the testing authority before issue.

Apart from purely mechanical breakages, the most frequent source of trouble appears to be due to leakage of the electrolyte between the glass and the platinum leading-in wires at the sides of the main electrolytic cell.

Several meters have been constructed which depend for their action on the deposition of copper, but such examples as the authors have examined were not worth serious consideration.

Watt-hour Meters.

As stated previously, these are the only true energy meters.

Most good direct-current watt-hour meters are, with slight modification, equally suitable for alternating-current working, but alternating-current meters are not necessarily suitable for direct current, as many of them depend for their action on the principle of the induction motor.

Direct-current Watt-hour Meters.—With one or two well-known exceptions, these are all of the true dynamometer type, and usually have rotating or oscillating volt-component coils. A notable exception is the Aron clock meter, in which the volt-component coils are fixed on the ends of two clock pendulums swinging in the magnetic field of the current-component coils; this arrangement is reversed in the latest shunted type of meter.

The most general form of dynamometer watt-hour meter consists

of an armature—which may have either an open, or a closed circuit winding—revolving in the magnetic field produced by one or more coils carrying the main current. The well-known Elihu Thomson meter was the prototype of this class. The mechanical friction is usually counterbalanced by a slight torque due to the magnetic field of a small coil placed in series with the armature; although this compensating torque varies as the square of the voltage applied to the meter, it is sufficiently constant for all practical purposes. In one well-known modification of the revolving armature type of meter, the armature, instead of revolving, merely oscillates through an angle of about 30°. The use of a commutator is therefore unnecessary, as the armature need only consist of a single coil; the shunt circuit is never completely interrupted, but the current through the armature is periodically reversed by an ingenious combination of an electrically operated two-way switch and a potential resistance. As the connection between the oscillating spindle and the counting train is purely electrical, the latter may be fixed at any reasonable distance from the meter.

An electromagnetic device for operating the counting train has been employed by a well-known English firm of instrument makers, the object, of course, being to eliminate the friction due to the counter, etc., by operating the train from an independent electrical source of energy, instead of from the operating portions of the meter.

The chief objection to the electro-mechanical operation of the counting train is the necessity for employing ratchet gears. A thoroughly reliable pawl and ratchet gear, suitable for this class of work, is by no means an easy thing to design. The adjustment also requires great care, in order to avoid errors due to slip, resulting from the spring and inertia of the moving parts.

The oscillating type of meter is naturally somewhat complicated, and faults are rather difficult to locate, but apart from these objections, meters of this type are remarkably accurate, and as they are usually well made, the accuracy is maintained over long periods, unless there is any change in the strength of the permanent magnets.

These meters are not suitable for use on alternating-current circuits.

The simple revolving armature type of dynamometer watt-hour meter with closed circuit armature has many good features, and if properly designed, and sold at a reasonable price, should be a serious rival to the mercury motor ampere-hour meter. The authors therefore consider that there is a large future for this class of meter.

The main sources of trouble in practice with dynamometer type watt-hour meters, are :—

Commutation.
Brushes.
Permanent brake magnets.
Bottom bearing.
Cramped design.

The small diameter commutators so frequently used appear to the authors to be very unsuitable, and probably better results are obtained with robust commutators having a greater number of segments, connected to multi-coil armatures of fairly large diameter. In the case of one well-known type, the meters are fitted with easily removable commutators, and the general details of the arrangement appear to be very good, but there is always the possibility of altering the relative position of commutator segments and armature coils, with a resulting alteration in the calibration of the meter. Unless they actually break circuit, which should, of course, be impossible, there appears to be no reason why the brushes should cause sparking on the commutator; probably the best forms of brushes are those making a number of separate and independent contacts, the pressure of the brushes on the commutator being controlled by special springs, and not dependent in any way on the natural springiness of the brushes themselves.

Bottom, or footstep bearings, are a frequent source of trouble. Owing to the comparatively heavy weight of the rotating portion of the meter, it is essential that this bearing should be very well made; only the finest jewels should be used, and experience would appear to show that a rounded or spherical-ended shaft is to be preferred rather than a pointed one. There appears to be scope for the design of a reliable ball-bearing for this purpose.

The removable spindle tips used by one well-known firm are a distinct advance.

The cramped design of these meters is responsible for most of the troubles in connection with the initial calibration, and also the permanency of the calibration, since permanent magnets will not withstand the severe conditions which it imposes.

When great accuracy is required, it is necessary for this type of meter to be wound astatically, and for certain working conditions it is in any case absolutely essential. Within the limits of ordinary house-service accuracy requirements, this special and expensive form of winding is not necessary, and where the local conditions necessitate the use of astatic meters, it is better to use the type referred to below.

Clock Meters.

The well-known Aron meter is the only one that will be referred to, as there are not, so far as the authors are aware, any other reliable meters of this type in use.

This meter is probably the most complicated (mechanically) and, at the same time, most accurate and reliable watt-hour meter made; it is a true dynamometer, and may, with slight alteration, be used for a wide range of measurements, both direct and alternating, and on either simple or multi-wire circuits. The principle of these meters depends upon the differential action of two clocks which are driven by a common main spring, electrically wound. The escapement train of each clock is connected to a common spindle through a suitable differential gear, the

common spindle being further connected in a special manner to the ordinary integrating dials.

The differential gearing is so arranged that as long as both clock trains are running down at the same rate, there is no rotation of the common spindle. This condition, however, is not attained when both pendulums are swinging with the same periodicity, since in order to avoid resonance effects, the wheel gearing one train to the differential has one more tooth than the corresponding wheel of the other train.

The pendulum bobs of the two clocks are formed of coils into which the current is led by suitable flexible connections, and these coils swing in the immediate vicinity of other fixed coils. The resulting magnetic reaction between the fixed and movable coils causes a variation in the relative periodicity of the two pendulums, and consequently in the rate at which the two clocks run down.

There are several patterns of the Aron meter, but the main differences between these are the methods of connecting the pendulum coils. The direct-current total-current type, and all alternating-current meters have the pendulum coils in the volt or pressure circuit, whereas in the direct-current shunted type, the pendulum coils carry a portion of the line current. The shunted type of meter cannot be used on alternating-current circuits.

Advantages of Aron Meters.—True watt-hour meters.

Astatic, and therefore not affected by stray fields. (This is not strictly correct in the case of polyphase meters, for the currents in the pendulum coils differ in phase by 120°. It therefore follows that stray alternating magnetic fields may affect the pendulums to an unequal extent ; but in practice errors in registration due to this cause are hardly noticeable. Polyphase meters are not affected by unidirectional fields, or even by alternating fields having a periodicity differing from that of the meter circuit.)

Contain no iron or permanent magnets. (In the direct-current shunted type the volt coil flux is concentrated by means of laminated iron stampings forming a definite magnetic path.)

Not affected by momentary overloads or short circuits.

Temperature error, except in the shunted type, practically nil.

Accuracy practically constant at all loads and for long periods of time.

As a rule, some very definite indication is given when the meter is out of order, and it is very unusual for a gradual increase, or decrease, in the registration to develop, as is frequently the case with motor meters.

In the event of any slight mechanical fault developing, it is possible to remove the clockwork for the purpose of adjustment, and afterwards replace it without interfering with the calibration of the meter.

Disadvantages.—Testing is both difficult and tedious, and unless extreme care is taken with the tests, inconsistent results are obtained.

It is impossible to make a rapid time test at any particular load, or

even to ascertain quickly whether the meter is working approximately correctly, unless the load is a fairly heavy one.

It is very difficult to avoid a slight creep, either forward or backward, which may cause apparently considerable errors, when working either on very low loads or with long intervals on open circuit.

It is essential that the meters should be fixed perfectly plumb, and if mounted on wooden boards, trouble may arise due to the warping or shrinking of the wood.

Poor insulation of the commutator; this occasionally results in carbonisation and partial shunting of the pendulum coils, the meter then registering slow.

Pitting of the Pendulum Arbor Pivots.—This is a particular and rather frequent source of trouble. It appears to be due to chemical or electrochemical action, and is occasionally very marked, the pivots being reduced to less than a half of their original diameter. The action is confined entirely to the back ends of the arbors, and although it may, to a certain extent, be accelerated by the immediate proximity of the pendulum coil leading-in wires, it is doubtful if these are the primary cause of the trouble. A more likely explanation is chemical action caused by the vulcanised fibre blocks used for insulating the terminals of the pendulum leading-in wires. The insulation of the winding gears occasionally breaks down, due to the same cause. The experience of the authors leads them to consider any form of vulcanised fibre to be unsuitable for use in the construction of meters and instruments, etc.

Owing to the somewhat complex details, very careful construction and adjustment are necessary, or otherwise mechanical faults are apt to develop.

The location of faults is rather a difficult matter, and repairs are expensive, owing to the skilled workmanship required. The house-service type of meter is rather bulky, and not at all convenient for many situations, and the price is also a deterrent to the use of these meters for small installations.

Total-current and Shunted Direct-current Aron Meters.

The total-current type is the only one suitable for house-service conditions, and is the best type for station work up to about 2,000 amperes. Above this size the use of the shunted type is quite legitimate, provided that the necessary precautions are taken.

The advantages of the shunted type are:—

Connections are much simplified, as the shunts may be joined in circuit at any convenient place, and connected to the meter by means of comparatively small leads. Severe mechanical strains on the meter are also avoided.

The meter may be removed for testing or adjustment without disturbing the station circuits.

If the resistance of the shunt is carefully measured, the meter may be tested with a small current on a shunt of higher resistance giving

the necessary voltage drop, and by this means, long time tests may be conducted in the test-room with great accuracy and ease, and with quite a small expenditure of energy.

The disadvantage of the shunted type are :—

The relatively high temperature coefficient, which is about 0·13 per cent. per deg. F.

The possibility of error due to the various contacts in the pendulum circuit working loose. There are about twenty-four clamped connections in a meter, and as the drop on the shunt at full load is only 0·2 volt, troubles due to bad contacts are only a matter of time, and are much accelerated by the temperature variations and vibrations encountered in a generating station. Experience has proved that for reliable working it is absolutely essential that most, if not all, of these connections should be soldered ; neglect of this precaution means that the meter will gradually register slower, no matter how carefully calibrated.

After considerable experience with most makes of watt-hour meters, the authors consider that a type free from permanent magnets, such as the Aron meter, is the only type capable of withstanding the severe conditions which exist in large direct-current generating stations. Overloads and external magnetic fields are sufficient to destroy calibration of all meters containing permanent magnets.

Mercury Type Watt-hour Meters.—There are not many watt-hour meters of any note in which mercury is used. Mercury is a necessary evil in certain successful types of ampere-hour meters, but its use in watt-hour meters is, in the opinion of the authors, very undesirable. Their experience is that this type of meter is very unreliable, and that the mercury troubles appear to be more pronounced than in the ampere-hour type. Most mercury watt-hour meters are shunted, and many calibration errors are no doubt traceable to this fact.

Shunts to Mercury Meters.

As previously stated, it was usual, up to a few years ago, to construct mercury motor type ampere-hour meters to carry the full current of the circuit through the mercury bath in all sizes below 100 amperes, and occasionally in even larger sizes. It is now usual to shunt the mercury bath for currents of very much lower value, one firm shunting even the 5-ampere meters, the shunt, in this instance, providing the only means for adjusting and calibrating the meters. It is open to question whether the use of these shunts is desirable, and it seems probable that any slight advantage gained by their use is outweighed by the attendant disadvantages.

The possible advantages are :—

(*a*) Reduced temperature error.
(*b*) Less liability to damage through momentary overloads and short circuits.

(*c*) Circuit not opened in case of mercury chamber becoming empty.

(*d*) Possibility of using a smaller and lighter armature, with a correspondingly smaller air-gap, and reduced speed.

The main disadvantages are :—

Liability of considerable error due to change in mercury resistance; the mercury bath is in parallel with a solid metal shunt of practically constant resistance (neglecting temperature coefficient), whereas it appears to be very probable that the resistance of the mercury bath may be a very variable quantity.

Item (*c*) above, while an advantage in one sense, is also a disadvantage, as the meter may be gradually slowing down, due to oxidation or leakage of the mercury, without any external evidence of the fact.

The danger of serious changes in the calibration due to variation in contact resistance between the shunt and the bath circuits.

Speaking generally, it may be safely said that shunts are always more or less undesirable on any type of meter, but particularly on service meters; and their use should be avoided as much as possible for all meters not exceeding 1,000 amperes current capacity.

Tramcar Meters.

The use of meters on tramcars has been much discussed during the last year or two, and many tramway departments have been experimenting with a comparatively small number of meters. So far, however, little has been said as to the existence, or otherwise, of a meter suitable for this particular class of work. The authors' experience leads them to form the definite opinion that there is not, at the present time, on the market, a meter capable of withstanding for any length of time the severe conditions obtaining on a tramcar.

That these conditions are exceptionally severe is sufficiently proved by the condition of meters that come into the test-room for checking (and usually repairing), after having been in commission for comparatively short periods.

Commutator type watt-hour meters are not suitable for car work, partly owing to the weight of the moving parts and the short life of the bottom bearing, and also owing to the violent sparking on the commutator caused by the excessive vibration. Owing to the lightness of their revolving parts, and the cushioning effect of the mercury, there is no doubt that the mercury motor ampere-hour type of meter gives the best results for this class of work. At present, however, the enormous momentary overloads, and the excessive vibration, are quite sufficient to alter the strength of any permanent magnets, and even when a very large proportion of the current is shunted, the life of the mercury is very short. The shunting also causes considerable inaccuracies, as the meter gives no indication of not working properly long after the accuracy has completely disappeared.

Whether any material benefit is derived from the use of meters on cars is a very controversial question, and quite outside the scope of this paper.

ALTERNATING-CURRENT METERS.

These may be sub-divided into "dynamometer" and "induction" types. The dynamometer type is, as a rule, suitable for alternating- and direct-current circuits, but the induction type probably represents at least 75 per cent. of the total sales of alternating-current meters.

The commutator type of dynamometer meter is suitable for alternating-current circuits, and should be capable of development as a standard type, but the error on low power factors is, as a rule, rather considerable on the low-voltage ranges, owing to the high inductance of the armatures, unless neutralised by eddy currents. This is rather a serious matter in the case of 100-volt meters working off the secondaries of pressure transformers.

The Aron meter is perhaps the best example of a universal dynamometer watt-hour meter. Owing to the high resistance of the pressure circuit, and the relatively large proportion which is non-inductive, the error on low power factors is not very great although, as might be expected, the meter has a tendency to register fast on lagging current loads, unless eddy currents are present, in which case it may actually register slow. Experiments have shown that this meter can be used on any frequency and wave-form, the only portion requiring any special adjustment for different frequencies being the winding gear.

For station work and heavy service conditions, where accuracy and reliability are essential, the dynamometer types of meter are to be recommended, but for ordinary service work, or even on switchboards, the induction type is now almost universally used. Induction meters have the great advantages of small size, lightness, cheapness, ease of adjustment, and fairly constant calibration, provided that the strength of the permanent brake magnets does not vary to any appreciable extent.

The shunt, or volt coil losses, in the induction meter are very much lower than in the dynamometer type, but this is mainly due to the extremely low power factor of the coil circuits, and probably also to the fact that, as a rule, the whole of the pressure circuit consists of active turns, whereas in the case of dynamometer meters a large portion of the pressure circuit is merely dead resistance.

The great objections to the induction type are, the small driving torque and the variation in accuracy with varying wave-form. In several recent designs, however, the torque has been considerably increased.

For any particular wave-form and frequency, the quadrature may be very accurately adjusted, and, moreover, if necessary, this adjustment may be effected in conjunction with a current transformer.

The temperature error is comparatively small, since both driving and brake torques are due to eddy currents generated in the same armature.

Torque of Induction Meters.—Endeavours are now being made to obtain a maximum driving torque with a minimum shunt coil loss. This is quite right in moderation, but there is a danger of its being overdone. Shunt losses are reduced by the use of a leakage field instead of a direct field for the driving component of the volt flux; consequently the meters are more susceptible to magnetic disturbances. In the case of polyphase meters the accuracy is also seriously affected.

It is questionable whether there is any advantage to be gained by pushing the torque beyond the limits necessary for swamping the friction errors, since if the speed is to to be kept within reasonable limits, it will be necessary to increase the strength or number of the brake magnets.

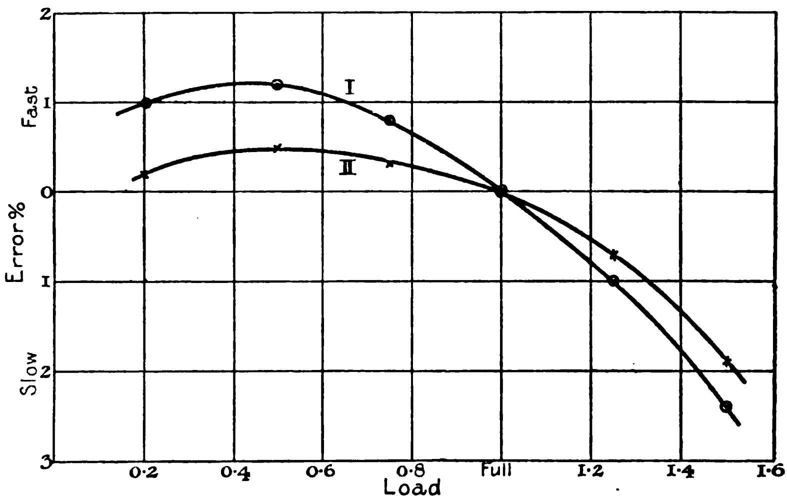


Fig. 2.

The driving torque, and, to a corresponding extent, the brake torque, may be increased by increasing the size and thickness of the disc or armature, but this means a heavy rotating part with a proportional increase in the wear and tear. Probably the better method is to increase the driving fluxes, and balance the increase torque by means of a stronger braking system, so as to maintain a fairly low speed; a more uniformly horizontal curve of accuracy will then be obtained.

Fig. 2 shows two curves characteristic of induction type meters. The rapid falling off in the speed of the meter at the overloads is due to the fact that the driving fluxes also act as braking fluxes, and the effect becomes very appreciable at the higher loads because this brake torque increases as the square of the fluxes. The two curves are plotted from observations made on the same single-phase meter. Curve I. was

obtained by adjusting the permanent brake magnet so that a minimum braking effect was produced, and the speed of the meter at full load was then about 50 revs. per minute. Curve II. was obtained by adjusting the magnet so that the maximum braking effect was produced, and the speed of the meter at full load was about 30 revs. per minute. It is seen that the motor gives a more uniform curve of accuracy when the braking effect of the permanent magnet is increased. It may be mentioned that in plotting the curves the meter was assumed to have no error at full load in both cases.

Alternating-current meters are essentially of the watt-hour type. The suggestion * has been made that an alternating-current ampere-hour meter might be desirable for the purpose of penalising consumers on whose circuits the power factor is very low. Apart from the reasonableness or otherwise of this suggestion, which is outside the scope of this paper, there are many difficulties in connection with the manufacture of a reliable alternating-current ampere-hour meter, and, moreover, it is a comparatively easy matter so to calibrate a meter of the watt-hour type that it shall register as fast as may be desired on inductive loads. This result may be obtained on either a dynamometer or an induction meter, by merely shifting the phase of the flux due to the volt circuit coil relatively to the applied voltage.

The best way of making the quadrature adjustment in induction meters is to test the meter with a lagging and a leading power factor, and also at unity, say, 0·5 lagging, unity, and 0·5 leading. When the meter has been adjusted until the error under these three conditions becomes approximately the same, the quadrature may be regarded as correct, although if checked with an indicating wattmeter of the dynamometer type, it may be found that the meter has a slight creep when the wattmeter reads zero, the explanation of this being the error in the indicating wattmeter caused by the inductance of its pressure circuit. The term "power factor" in the above is intended to represent the ratio $\dfrac{\text{watts}}{\text{volt-amperes}}$.

Dynamometer meters are unsuitable for working off current transformers if intended to be used on circuits having very low power factors; because the error due to the inductance of the volt coils is intensified by the effect of the lead in the transformers. This error can, to a great extent, be corrected by means of eddy currents induced in suitable closed circuits or masses of metal, or even by shunting the series coils, but the meter will only then be suitable for one particular frequency, and the accuracy will be affected by changes in temperature and wave-form, etc.

Tests made on a dynamometer meter of a well-known make showed that the eddy currents induced in the metal cover were more than sufficient to counterbalance the inductance of the armature. The meter registered slow on inductive loads with the cover on, and fast when the cover was removed.

* *Proceedings of the Institution of Electrical Engineers*, vol. 42, p. 616.

The temperature error in dynamometer meters is, as a rule, fairly high. The primary cause is the variation in resistance of the brake disc, and it is possible that this might be compensated for, to some extent, either by the use of resistance wire having a high positive temperature coefficient in the pressure circuit, or perhaps a better method would be

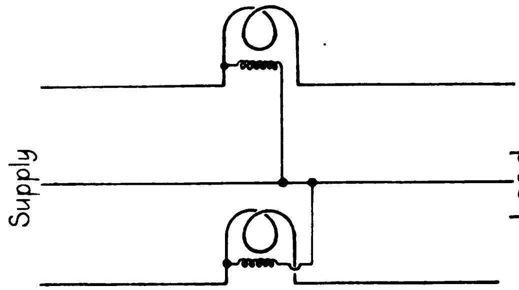


FIG. 3.

to shunt the series coils by a resistance having a negligible temperature coefficient. The shunt method would, of course, have to be used with discretion even for direct-current work, as it is probable that errors might be introduced when working on fluctuating loads, due to want of balance in the inductances of the two circuits. In the case of meters

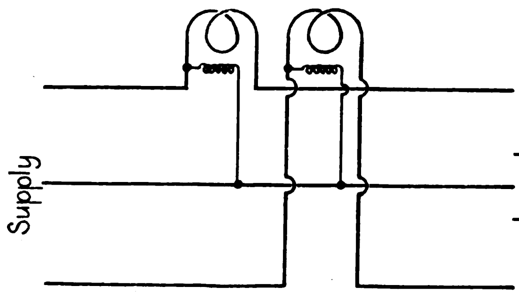


FIG. 4.

intended for use on alternating-current circuits, it might be possible to apply this method of adjustment to correct for the lag of the volt coil current, and even for the lead in a current transformer.

POLYPHASE METERS.

Polyphase meters are now extensively used for measuring the energy on 3-phase circuits. Many of the so-called polyphase meters

are only single-phase meters, and their measurement of the 3-phase energy is based on one or more of the following assumptions :—

(*a*) Sine waves of current and volts.
(*b*) Exact balance of current on the three phases.
(*c*) Exact equality of volts between the three phases.
(*d*) Phase angle of exactly 120° between phase voltages and between phase currents.
(*e*) The possibility of creating an artificial neutral or star-point.
(*f*) The possibility of obtaining a resultant current in phase with the voltage between phases.

In practice the possibility of obtaining any of the above conditions is always open to considerable doubt, and the only reliable meters are those consisting of a combination of two or more single-phase elements, the construction and arrangement of the combination to be such as to admit of being accurately tested on a single-phase circuit.

The only reliable and satisfactory method of measuring the power in a 3-wire 3-phase system under all conditions of load and power factor is the well-known 2-wattmeter method, and the equivalent arrangement of two watt-hour meters is the most satisfactory method of measuring the total amount of electrical energy supplied to a 3-phase 3-wire system. On a 4-wire system three meters are required, or, generally speaking, $(n - 1)$ meters where $n =$ number of wires. This rule is applicable to either a direct-current multi-wire system or to an alternating-current system with any number of phases, provided that the minimum number of wires be used.

For convenience and simplicity it is usual for the two necessary watt-hour meters to be contained in the same case and to integrate on a common set of dials, but when used under these conditions it is essential that the requirements of the 2-meter method should still be fulfilled.

Figs. 3 and 4 are the arrangements described above.

The following set of diagrams (Figs. 5 to 9) show some of the methods in use for metering the energy on so-called balanced 3-phase systems.

Fig. 5 is intended to be the equivalent of connecting the pressure terminal of a single-phase meter to the star-point of a 3-phase system, when the actual neutral is not available. Equality of phase current and phase volts is assumed.

A constant multiplier of 3 will be required in the gearing.

This method is only applicable to meters of the dynamometer type.

Fig. 6 is a modification of the previous arrangement applicable to induction meters, and is generally used in conjunction with a pressure transformer.

A constant multiplier of 2 is necessary in gearing if the meter is calibrated for the line voltage.

Considerable errors may be introduced if the phase voltages are

not equal, and this is particularly the case when the power factor of the circuit is low.

Fig. 7.—In this case the calibration is based on the fact that in the hypothetical 3-phase circuit, there is an angle of 30° between the phase voltage, and the resultant voltage between any two phases.

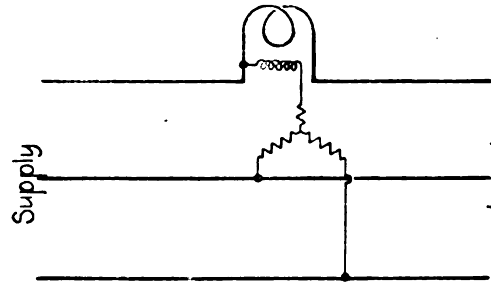


FIG. 5.

And since in an induction type of meter the mean torque is proportional to F_v F_a sin θ where $\theta =$ the angle between the current and volt coil fluxes, the maximum mean torque is therefore attained when $\theta = 90°$.

In an ordinary single-phase meter this angle exists when the power factor of the circuit is unity, if the quadrature adjustment is correct.

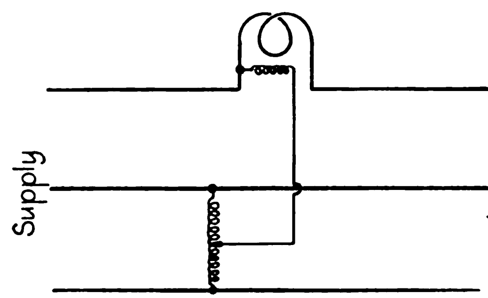


FIG. 6.

In the case of meters arranged for connecting, as in Fig. 7, the pressure coil flux is arranged to lag 60° only behind the current flux, when tested on a circuit having unity power factor, and the other 30° is made up by the angular displacement of the resultant voltage.

Uniformity of phase-voltage, and exactly 120° displacement between phases are assumed.

The gearing constant is $\sqrt{3}$.

This is, undoubtedly, the worst example of inadmissible connection.

Not only are the probabilities of error very great (they amount almost to certainties) but the meter, as calibrated, is extremely difficult to test accurately, and it is almost impossible to test it correctly over a very wide range of power factors.

If the free end of the volt circuit is connected to the wrong phase, which may very easily be done, the meter will only read one-half

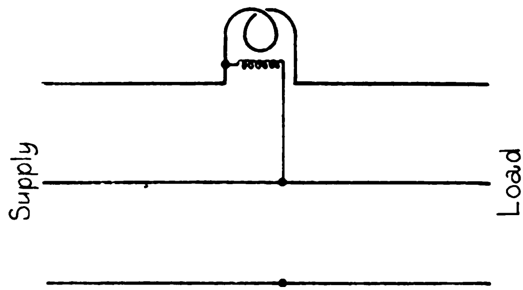


FIG. 7.

of what it should do, *i.e.*, the angle between the volt and current fluxes will be $60° - 30° = 30°$ instead of $60° + 30° = 90°$.

Fig. 8.—This method is based on the assumption that the power in a 3-phase balanced circuit may be expressed as $\sqrt{3} \,.\, V \,.\, A \,.\, \cos\phi$.

The mean torque in the meter is proportional to the product of the volts between any two phases, the vectorial sum of the currents in

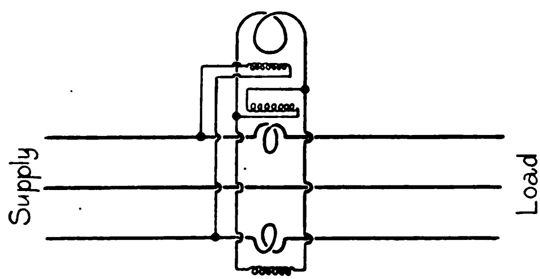


FIG. 8.

the same two phases, and the cosine of the angle between the resultant current and voltage. Since the circuit is assumed to be a balanced one $A = A_1 = A_2$, and the sum $= \sqrt{3}\,A$. This resultant current is in phase with the resultant voltage between phases when the equivalent power factor of the system is unity. The total power is therefore represented by $V \times \sqrt{3}\,A \cos\phi$, and the mean torque of the meter is proportional to this quantity.

If used in conjunction with two current transformers, a standard type of meter with only one current coil may be used, but on low-voltage circuits it would be possible to dispense with the current transformers, if a special duplex winding were provided on the meter; but the transformers form the better arrangement, and, moreover, the

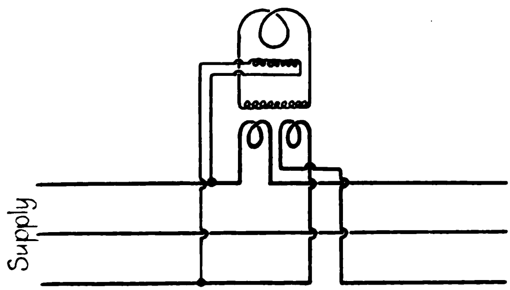


FIG. 9.

meter will read direct without the necessity for a multiplying constant in the gearing.

Equality of current and phase angles are assumed.

This is probably the best of the various compromise arrangements.

Fig. 9.—This is a special case of the previous example. Instead of

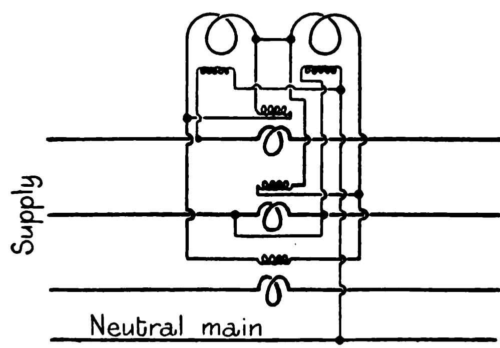


FIG. 10.

superimposing the currents on the coil of the meter, a transformer having one secondary and two primary windings is used. The secondary current is therefore proportional to $\sqrt{3}$ A, and is in phase with the resultant voltage when the power factor of the system is unity.

Fig. 10 shows a method of superimposing the third phase current upon the two meters used for measuring the energy in a 3-phase 4-wire circuit. In this case the volt coils of the meters are connected

as shown between two of the lines and the star-point instead of between the lines. The fluxes are therefore proportional to the phase voltages, and as the connections of the third current winding are reversed, the volt factor becomes $-(v_1 + v_2)$, that is v_3.

Permanent Magnets.

With the exception of the Aron and possibly one other type, all electromechanical meters depend for their action upon the use of permanent magnets. In ampere-hour motor meters, these magnets provide both the driving and the brake torques, and in all motor watt-hour meters, either direct current or alternating current, they provide the controlling or brake torque.

It will thus be seen that the so-called permanent magnet constitutes a most important feature of practically every type of motor meter, and naturally should therefore be both well made and thoroughly reliable.

There is no comparison between the use of permanent magnets in indicating instruments of the moving-coil type and in integrating meters. In indicating instruments the magnet is usually very long, the air-gap is extremely small, demagnetising influences are comparatively slight, and, further, the readings of the instruments are proportional to the magnet pole strength. But in the case of integrating meters the magnets are often very small, with a correspondingly reduced magneto-motive force; the local demagnetising influences are of considerable magnitude, and may at times even be abnormal; and the registrations of the meter are, as a rule, inversely proportional to the square of the pole-strength. Even well-designed magnets of good quality may have their action considerably nullified by the influences of stray magnetic fields, produced by the current in either the coils of the meters or in neighbouring conductors.

It does not appear to be realised how intense may be the magnetic fields produced by the series coils of a meter in case of a short circuit or momentary overload, and consequently the means taken to shield the magnets from the effects of such fields are quite inadequate, and, in some cases, even help to concentrate the action of the stray fields on to the permanent magnets.

If the condition of damaged meters removed "off-circuit" is any criterion, there is no doubt that the overload tests usually specified are not to be regarded as the equivalent of actual service short-circuit conditions.

The effect of local stray fields in large generating stations is enormous, and is far greater than is generally realised. One of the authors has seen a dynamometer watt-hour meter stop at about one-third load, and actually reverse at one-quarter load, due to the effect of a stray field, which was obviously stronger than the field of the meter's own current coil.

As a further instance of the effect of these stray fields, the curve given in Fig. 11 is very interesting; it represents the varying error in

the readings of five recording voltmeters which were contained in cast-iron cases, and it will be noticed that the variations, when plotted, give an almost exact reproduction of what was probably the station load curve at the time.

It will therefore be understood how essential it is that the magnets in station meters should be shielded as completely as possible, and, in addition, the torque-producing portions of the meters should be astatically wound. It is frequently supposed that alternating meters are not affected by stray fields, and this would be true if the stray fields were undirectional and the permanent magnets were efficiently

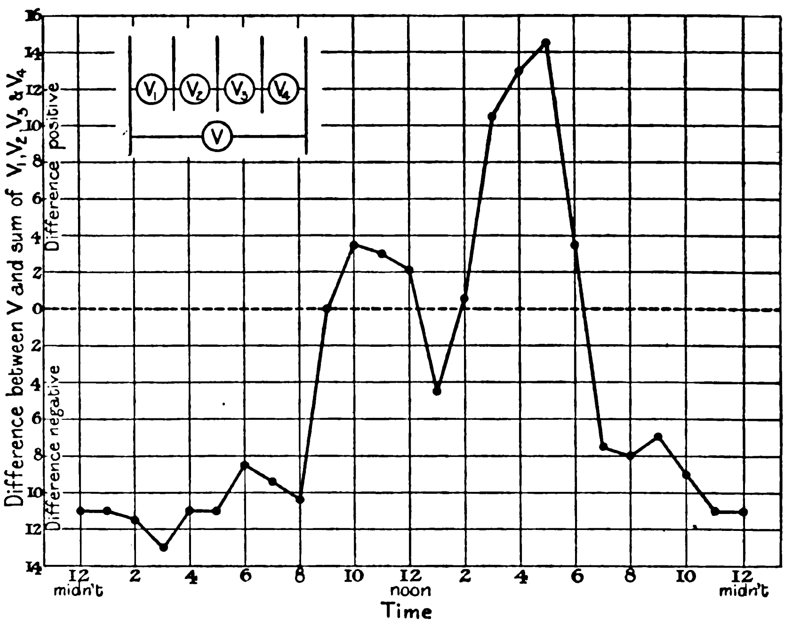


FIG. 11.

shielded; but the fact must not be overlooked that alternating-current meters and instruments may be affected by alternating magnetic fields in synchronism with their own self-induced fields.

This effect is very noticeable on indicating instruments when the frequency of the stray field varies slightly from that produced by the current through the coils of the instrument itself. Under these conditions the pointer will swing over a portion of the scale with a periodicity equal to the difference between the periodicity of the superimposed fields. This effect must also be present in integrating meters under the same conditions, but, of course, is not observable.

Ampere-hour meters are not, as a rule, affected to the same

extent as watt-hour meters, by variation in the strength of the permanent magnets, since a reduction in the brake torque proportional to the square of the variation in the pole-strength is partly counterbalanced by a reduction of the driving torque proportional to the variations in the pole-strength. This, of course, does not apply to meters in which there are separate magnetic circuits for producing the driving and braking torques respectively.

In contrast to the short magnets previously referred to, are the long magnets now used in the leading types of mercury motor ampere-hour meters. The advantages of having long brake magnets in alternating-current meters is also beginning to be realised.

METER TESTING.

Mention has previously been made of some of the sources of errors in meters as at present designed. Certain of these errors cannot be wholly eliminated, and are only made negligibly small under specified conditions of working.

It must be remembered that, as a rule, an electricity meter in use has no check on its registrations, it being the sole instrument responsible for the measurement of the energy consumed on its particular circuit. When a man buys a watch for ordinary purposes, he has little need to have it periodically tested, for if any irregularities develop, he is at once made aware of the fact because his watch is not the sole instrument responsible for the measurement of time.

The revenue of an electricity supply undertaking is derived mainly from the registrations of the consumers' meters. This is based on the registered total, and some of the meters may register fast, thus tending to balance those registering slow; but on a point of equity it is clearly unfair to make one consumer pay for the energy used by another.

In the case of private installations, energy meters become, as a rule, mere switchboard ornaments, in that they are rarely, if ever, tested, and their accuracy is therefore unknown. If it is necessary to instal meters in private installations it must also be necessary to know their accuracy.

Generally speaking, the main objects of having meters tested by testing authorities is to ascertain that the errors of registration are within the legal or specified limits, and that the meters run satisfactorily under load conditions. In certain other cases, when the meters are not used for the measurement of energy supplied to a consumer, but are used for the testing of plant, it is the actual errors or corrections for the meters which have to be determined very exactly, legal or specified limits of error not then being in question.

In the opinion of the authors, no effort on the part of the designers or the manufacturers should be spared to bring the errors down to the lowest possible value. Until a satisfactory, commercial meter can be produced at a reasonable price and having an error not exceeding 1 per cent. under all reasonable conditions of working, there is room for improvement in design and construction.

It is, the authors consider, distinctly inadvisable and a retrograde step to extend the legal permissible limits of error, unless it can be shown that meters cannot be brought up to this standard. The authors' experience is that meters can be satisfactorily manufactured to even closer limits than the legal specification, and any extension of the limits of error is therefore a temptation to the manufacturers to relax their efforts for the production of a really accurate meter. Generally speaking, the errors increase after installation, and large initial errors may mean abnormally large errors after continued service. On the other hand, small initial errors are conducive to reasonable accuracy over a considerable period of time.

The following section is confined to that branch of meter testing which consists in the determination of the errors of registration.

All the instruments used for verification purposes should be sub-standards,* and should be verified at frequent and regular intervals by comparison with secondary standards.* It will be obvious that the errors of the sub-standards must be known to within much smaller limits than the limit of error allowed in the meters under test. It is however, not an uncommon experience to find meters being tested with ammeters and voltmeters which can only be relied on to within 2 or 3 per cent., giving a possible error of 4 to 6 per cent. in the product of the readings of the two instruments. Another common mistake is to use the same range on, say, an ammeter, to test the meter at all loads from full load or over, down to $\frac{1}{10}$ load, so that the lower readings are taken on a very small length of the ammeter scale. This procedure gives rise to considerable errors of observation at the lower loads independent of the accuracy of the ammeter, and the fact must not be overlooked that it is often of greater importance for the meter to be accurate at $\frac{1}{2}$ or $\frac{1}{4}$ load than at full load. A consumer's meter on a lighting load is probably rarely subjected to full load-conditions.

The connecting up of meters for testing is of considerable importance, especially if the current capacity of the meter is as high as about 300 amperes or more. Most meters have a temperature coefficient, and in some cases this is as high as 0·25 per cent. per deg. F. The temperature of the inside of the meter case, which is the important temperature, depends not only on the outside temperature, but also on the rate of generation of heat in the coils. With watt-hour meters it is generally understood that they have their shunts fully excited for at least an hour before observations are commenced, so that the meter may be properly warmed up. With heavy current meters, however, there is often more heating from the series coils than from the shunt coils, and this becomes quite serious if there are bad contacts in the series coils connections. Much heat is generated at the bad contacts, and this is quickly conveyed to the interior of the meter by the good heat-conducting properties of the copper. Despite this fact, however, extremely poor connections may often be observed in test-rooms.

* As defined in the Engineering Standards Committee Specification for Ammeters and Voltmeters.

With heavy current meters it frequently happens that special cable ends are used for the connections to the series coils, in order to get the best possible contacts. In these cases there is often no other way of making really good contacts, and it is therefore essential that these connecting lugs, or others of the same type and dimensions, should be used for connecting the meter to the testing cables. It would obviously be of advantage to testing authorities and to meter users, if the terminals of meters were standardised, as it would not then be necessary to unsweat the lugs from the main cables every time the meters were removed for testing, standard lugs being then a part of the test-room equipment. For meters to attain the correct steady temperature, particularly those of large current-carrying capacity, it is necessary to have both shunt and series coils excited, the meter running, and to take care that no undue heating takes place due to bad contacts at the connections. With the meter actually running there is also the further heating of the brake disc due to the eddy currents induced in it, and in some types of meter it is the temperature of the brake disc which is all-important.

Two-circuit Connections for Testing.—A very little consideration of the matter will be sufficient to show that meters of large watt capacity cannot be tested in the ordinary test-room unless some special means are adopted for artificially producing the load conditions. This point is quite familiar to those connected with meter testing, but as many who send meters to be tested appear to think that they are put on actual load a brief allusion to the testing circuit may be of use. Take, for example, the testing of a direct-current meter of the Thomson type, having a capacity of 1,000 amperes and 500 volts. To test such a meter on actual load would require a 500-k.w. generating set, and a suitable load for it. The whole effect in the meter is, however, produced by a current of 1,000 amperes in the series coil, and 500 volts applied to the pressure coil. So far as the actual working of the meter goes, therefore, it is immaterial how the current in the series coil is produced, so long as it is maintained at the required value. For economy and convenience in regulation, the series current is supplied at a low potential only. Thus if 10 volts is the pressure of the current supply, the power required to test the meter under the equivalent of full-load conditions is $10 \times 1000 + \frac{500^2}{R}$ watts, where R is the ohmic resistance of the shunt coil of the meter—about 10 k.w. in all.

In the case of direct-current meters the current and pressure for testing purposes are best obtained from secondary cells, as greater constancy is then maintained than is the case when they are obtained from generators. A few cells of large capacity are required to supply the current for the series coils, and the requisite number of cells of small capacity to supply the pressure circuits.

For testing alternating-current meters the apparatus required is much more complicated than that required for continuous-current meters, it being necessary to provide means for adjusting the voltage, current,

frequency, power factor, and possibly also the wave-form of the supply. The accurate conduct of the tests is also more difficult, since alternating current cannot be obtained directly from cells, and the steadiness of the supply is thus governed largely by the constancy of the speed of running machinery.

The necessary apparatus required for testing alternating-current meters includes ammeters, voltmeters, and wattmeters, all of which should have their accuracies unaffected by changes in frequency and wave-form, and be of suitable capacities; a frequency meter, a phase-adjusting device, a means of telling whether the current is leading the voltage, or lagging behind it, and the necessary machinery for generating the alternating current.

It is necessary, again, here to emphasise the importance of accurate indicating instruments, and particularly in the case of the indicating wattmeter, this being, perhaps, the most important of the testing instruments used. A source of error in dynamometer wattmeters, and dyamometer watt-hour meters, which is at once most difficult to eliminate or to correct for, is due to the effect of eddy currents in portions of the instruments. From recent experience and tests carried out by the authors, they are of opinion that splitting the metal formers and supports in dynamometer wattmeters is not effective in eliminating eddy currents, and instruments of this type containing metal plates or formers, split or otherwise, will be liable to error introduced from the effect of eddy currents when the power factor is other than unity.

The accuracy of the ammeter and the voltmeter is of less importance than that of the indicating wattmeter.

Apparatus for Generating the Alternating Current.—Practically all modern alternating-current meters are of the watt-hour type, and hence, as in the case of direct-current tests, the two-circuit method of testing is employed. Unless suitable apparatus is installed, however, it is probably better, in cases where meters of only small capacities have to be tested, to use a single circuit of the correct frequency and voltage. More generally, however, arrangements have to be made for testing meters of large capacity for use on power circuits, as well as those employed for small lighting loads.

For the production of the necessary alternating current, one generator, with suitable transformers for the voltage and current circuits, or two generators of the same frequency, coupled rigidly together, one to supply the pressure and the other the current circuit, may be used. The generator for the current circuit may be either a low-voltage machine having the necessary current output, or, as is usually more convenient, it may be used in conjunction with a transformer having a low-voltage secondary winding. A transformer may also be used with the machine supplying the pressure circuits.

The method of regulating the current and voltage of the testing circuits is also important. If the loads on the machines are appreciable, compared with their rated output, it is advisable to work always with a

strong field. The load current on the machines produces considerable field distortion with weak fields, and the wave-form of the generators is liable to be changed thereby. The field circuit of the generator or generators should therefore only be used for regulation over small ranges. Wide changes in voltage for the pressure circuit may be obtained by using an auto-transformer or other transformer with suitable tappings on the secondary, and changes in the current in the series circuit may be effected by means of a regulating resistance in the secondary or meter circuit of the low-voltage transformer. There is always a temptation to regulate the heavy secondary current in the series coils by means of a rheostat in the primary of the low-voltage transformer, but this procedure should always be avoided as it leads to variation in the wave-form of the secondary. Other advantages are gained by connecting the regulating resistance in the secondary circuit of the transformer. If the series coils of meters were to be connected directly to the secondary, and the regulation carried out entirely on the primary, by generator field regulation, the secondary circuit being one of considerable inductance, the current wave would differ from that of the pressure wave producing it if the pressure wave were not sinusoidal. The resistance in the secondary circuit tends to remedy this, and in addition keeps the phase of the secondary current fairly constant relatively to the phase of the volts applied to the pressure circuit.

When a transformer is used to supply the pressure circuit, it is necessary to have the transformer provided with suitable tappings on the secondary, as previously stated, and not to regulate the secondary voltage by means of a resistance in the primary circuit, such resistance changing the wave as in the case of the transformer for the series circuit. It is also important to note that resistances must never be connected in series with the pressure coils of induction meters for the purpose of regulating the voltage applied to the coils.

Frequency Regulation.—The adjustment of the frequency presents no difficulty in these days of interpole motors, and speed regulation from 25 ∿ to 100 ∿ is quite easily obtained on one machine by motor field regulation. Alteration of the speed by means of resistance in the armature circuit of the motor is very inconvenient, as the speed of the machine is then seriously affected by alteration of the load.

Frequency Meters.—Frequency meters of the vibrating reed type are found to be quite satisfactory, and instruments indicating quarter-period differences may now be obtained.

Phase-adjusting Devices, and Adjustment for Power Factor.—When the current and voltage for testing alternating-current meters are supplied from two separate sources, the power equivalent can only be determined by means of an indicating wattmeter, and the equivalent power factor is obtained from the readings of the wattmeter, ammeter, and voltmeter. In order to be able to adjust the power factor to the required value, some reliable form of phase-adjuster is essential.

The term "phase-adjuster" is intended to designate any arrange-

ment of apparatus by which the phase relation of the volts and the amperes in the pressure and current coils respectively of the meter or group of meters, may be changed without appreciable alteration of the values of the volts and amperes in the circuit; choking coils and condensers are therefore excluded.

The following methods of phase adjustment may be employed :—

(*a*) Two alternators of the same frequency coupled rigidly together, but with the couplings so arranged that the phase of the E.M.F. of one armature may be altered relatively to that of the E.M.F. of the second.

(*b*) Two alternators as in (*a*), but with the stator, instead of the rotor, of one machine arranged so that it may be turned relatively to the stator of the second machine.

(*c*) A phase transformer (static induction motor), the stator (or rotor) being supplied with multi-phase current, and the rotor (or stator) used to supply either the pressure or the current circuit of the meters. By moving round the rotor into different positions, the phase at the rotor E.M.F. may be altered relatively to that of the stator E.M.F.

(*d*) A multi-phase choking coil or auto-transformer, provided with suitable variable tappings, and connections made by means of brushes or switches.

(*e*) In certain cases different parts of a 3-phase circuit may be used, giving phase differences of approximately 0°, 30°, 60°, and 90°.

Of the foregoing methods, (*b*)—two machines, one provided with a moveable stator—is probably the ideal device.

The voltage of the machine supplying the pressure coils, and the current from the machine supplying the series coils of the meters, can be adjusted quite independently of each other, and then the movable stator can be turned, whilst the machine is actually running on load, until the required reading on the indicating wattmeter is obtained.

Such a set of machines, manufactured by the British Westinghouse Company, has been installed in the School of Technology, Manchester, and has been in use for the last sixteen months, proving extremely useful and convenient for the purpose.

The set comprises two similar alternators direct driven by a continuous-current motor arranged between them on the same bed-plate (Fig. 12). The motor is a 400-volt interpole variable speed machine of 13 B.H.P., with a speed regulation of 500 to 2,000 revs. per minute effected solely by variation of motor field current. The alternators are 6-pole 3-phase rotating armature machines, and six slip-rings are provided on each so that the armature coils may be connected either star or delta. The larger of the two alternators has a rating of 5 k.v.a. at 25 periods (500 revs. per minute), and the smaller one 1 k.v.a. at the same speed, and both machines are designed to give 100 volts at this frequency. The larger machine is generally used in conjunction

with a Westinghouse 5-k.v.a. oil-cooled transformer giving a normal secondary load current of 1,000 amperes. This transformer has two primary and two secondary windings. The primary windings can be connected in series or parallel for 200 or 100 volts respectively, and in the same manner the secondary can be arranged for 10 volts or 5 volts. The usual connections are for 200 volts primary and 5 volts secondary, so that the load current taken from the machine is kept as low as possible.

The smaller alternator, which is used to supply the pressure circuits of the meters, is also used in connection with transformers when the voltage required differs considerably from the normal voltage of the machine. The field system, or stator of this machine, has been turned so as to fit into a circular seating on the bed-plate, and by means of wormgear may be turned through about 200 electrical degrees.

It is quite a simple matter to know if the phase of the voltage of the smaller machine is leading the phase of the current from the larger one or lagging behind it. By rotating the stator against the direction of rotation of the armature, the lead of the voltage is increased, or, by rotating with the direction of the armature the lead of the voltage is diminished, or the lag increased. Moreover, if any doubt exists as to whether the voltage is leading the current or lagging behind it, it is only necessary slightly to alter the position of the stator and to note the effect on the indicating wattmeter. If moving the stator against the rotation of the armature increases the reading on the wattmeter, then the voltage is lagging behind the current, and *vice versâ.*

The alternators are excited from secondary cells, and the result is a very steady supply of alternating current.

Device (*a*)—two machines with adjustable coupling—is not so convenient as the above, since it is necessary to stop the machines to make the adjustments for power factor, and the adjustments can only be made by trial, as the phase of the voltage derived from each machine is somewhat varied by the variation in the nature and magnitude of the load on it.

Device (*c*)—phase transformer—is a very convenient one, and is, perhaps, best suited to supply the pressure circuit. An ordinary 3-phase induction motor with slip-ring rotor may be conveniently used, and has been found by the authors to give satisfactory results. It is necessary to prevent the rotor turning round under the action of the currents, and to provide a fine adjustment for altering the relative positions of the rotor and stator.

In use the stator is connected to a 3-phase generator, and one phase of the generator is then used in conjunction with a low-voltage transformer to supply the current circuit, the rotor voltage supplying the pressure circuit. Unless a regulating transformer is used in connection with the rotor circuit, it is a little inconvenient to adjust the current in the series circuit, and the volts on the pressure circuit exactly, because, unless the rated output of the generator is very large compared with the load required, alteration of the load current in the series circuit will

vary the voltage applied to the pressure circuit, and alteration of the excitation of the generator will affect both the pressure circuit and the series circuit.

A combination of an induction motor and the two machines mentioned in method (*a*) would eliminate most of the disadvantages possessed by either method used separately.

The use of a single-phase generator with a single-phase induction motor is not very satisfactory. It is found that when the rotating field in the stator of the induction motor is produced by splitting the single phase, the rotor voltage varies with the relative position of the rotor and stator, and thus the voltage is not maintained constant when adjustment is made for power factor. The method is therefore inconvenient.

Induction phase transformers with suitable connections and rotor-adjusting devices may now be obtained from several makers, and it should be remembered that, within limits, the larger the rated output of the machine the more satisfactory will be the result. It was pointed out by Wild,* that with this form of phase adjuster the shape of the secondary wave will differ from that of the primary when the primary is not sinusoidal.

Device (*d*)—multiphase choking coil—is also a most convenient and satisfactory piece of apparatus if it is properly arranged and of ample dimensions.

A combined phase adjuster and voltage regulator of this type, possessing one or two somewhat uncommon features (probably because home made), has been in use for several years in the test-room of the Manchester Corporation Electricity Department, and has given excellent results. The construction and arrangement will be readily understood from the following brief description and reference to Fig. 13.

The main portion of the apparatus consists of an ordinary direct-current drum armature, having a lap winding and slotted core, and originally used in a 10-H.P. 4-pole 400-volt motor. The armature has been surrounded with tightly fitting annealed iron stampings in the form of annular rings, built up to a depth nearly equal to the length of the core, and compressed between strong gunmetal end-rings. Suitable ventilating gaps are provided at intervals and the bolts drawing the end-rings together are bushed to avoid the production of eddy currents. The 3-phase supply mains are connected to the armature windings at 6 equi-distant points, and consequently induce a rotating magnetic field in the armature and annular ring. The magnetic circuit is practically all iron, as the joints are very good.

The armature is mounted with the axis vertical, in a stand forming part of a switchboard, and the commutator, or upper end of the shaft, is utilised as the support for a free fitting bush on which two radial arms are fitted. These arms may be moved relatively to each other, and may also be clamped together in any required position.

* *Journal of the Institution of Electrical Engineers*, vol. 44, p. 224, 1910.

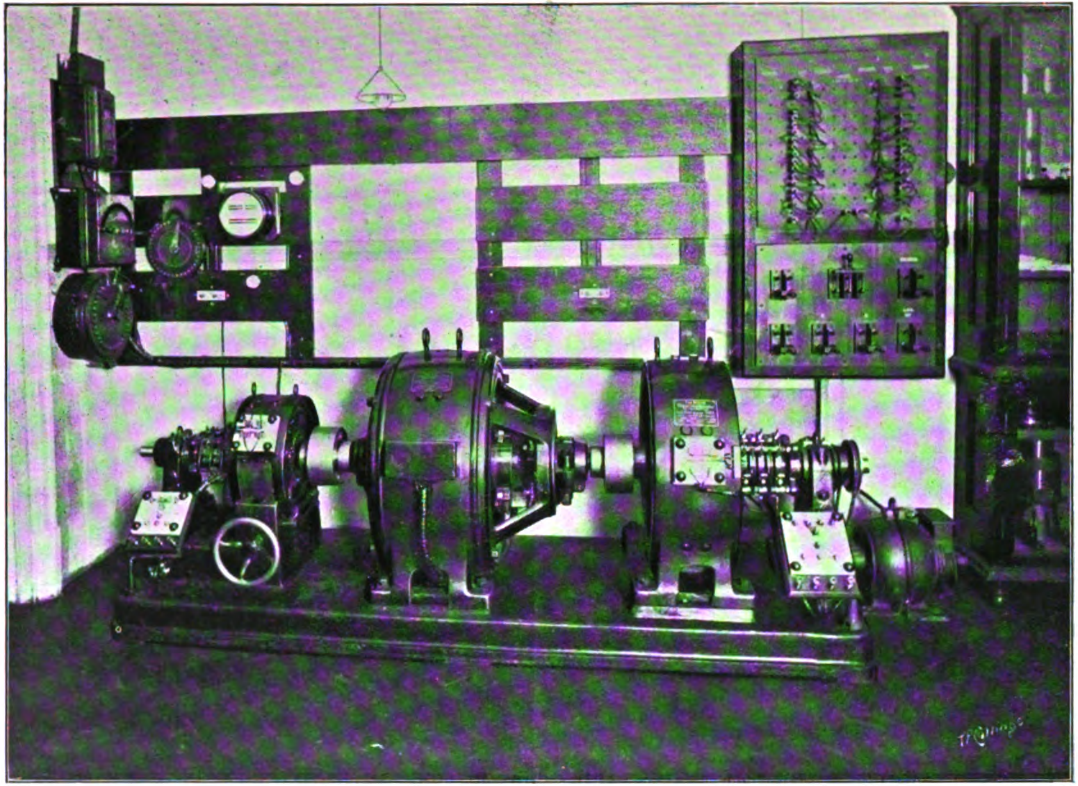


FIG. 12.

At the ends of the radial arms insulated brush-holder spindles are mounted, to which suitable brush-holders are attached. The brushes are of solid copper, and the portions bedding on the commutator are sufficiently thin to avoid bridging the insulation between segments. This is necessary as the brushes have to be moved over active

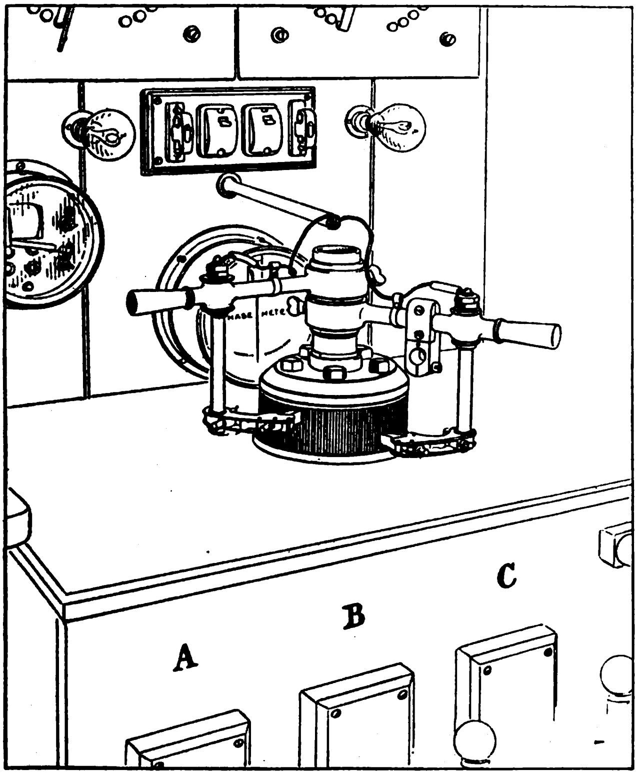


FIG. 13.

segments having an appreciable difference of potential between them.

It will thus be seen that by moving the radial arms relatively to each other, a large range of voltage adjustment may be obtained, and when the arms are clamped together, and the whole combination moved round the commutator, any desired phase displacement may be obtained between the voltage of the circuit fed from the movable brushes, and that of any other circuit connected to the same source of alternating current as the phase adjuster.

Usually only the two collecting brushes are used, but provision

is made for attaching a third. The apparatus also acts as an auto-transformer, and if the brushes are set with an angle of 90° between them, a pressure higher than the supply voltage may be obtained, the ratio being approximately $2/\sqrt{3}$, *i.e.*, sin 90°/sin 60° or 1·15. Any lower voltage may be obtained by moving the brushes nearer together.

The phase adjuster is used to supply the pressure circuits of the meters, the series circuits being fed from the low-voltage (about 20 volts) secondary windings of a step-down transformer, with the primary connected to the same source of supply as the phase adjuster. As both the primary and secondary windings of this transformer are in two sections, it is possible to obtain a fairly constant secondary voltage with a wide range of primary volts.

When the phase adjuster is supplied with 3-phase current at 364 volts between lines, the no-load current = 4·45 amperes per phase, and the no-load watts = 428 total. The ratio of the secondary volts to the primary volts on open circuit, with the brushes 90° apart = 420/364 = 1·15, this being in agreement with the theoretical value.

The adjustments for voltage and phase regulation are necessarily in steps, but a fine adjustment of the voltage is obtained by regulation of the alternator field, and the steps for phase adjustment are sufficiently small for practical purposes.

Records taken by the authors with an oscillograph show that even when an appreciable load is taken from the secondary or movable circuit of the phase adjuster, the secondary wave shows no apparent difference in shape from that of the primary wave.

With regard to the method of obtaining certain different phase relations by connecting the series coils of the meters to one part, and the shunt coils to another part of a 3-phase supply (as in (*e*) page 32), it may be pointed out that the theoretical phase-relations are much disturbed by the unbalanced nature of the load. This disturbance is particularly marked when connection is made to the neutral-point.

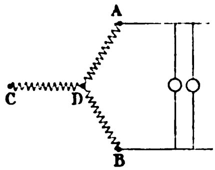
In this connection the results of some observations taken on the 3-phase alternator provided with the movable stator and previously described may be of interest.

The armature coils were star-connected, and the voltages and wave-shapes of the different parts of the armature circuit were tested on open circuit, and also when loaded with lamps between two of the lines as shown in Fig. 14.

Waves 1 and 2, Fig. 14, represent the E.M.F. waves taken between A and B on open circuit and when loaded with a current of 4 amperes, respectively. The E.M.F. wave between neutral D and the line on open circuit is not reproduced here, but is practically the same as wave 1. Waves 3, 4, and 5, were taken across A D, B D, and C D respectively, with the load on A B as shown.

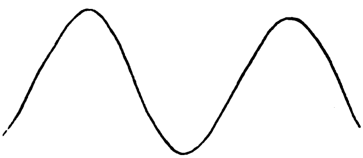
It will be noted that the voltages (Table I.) and also the waves between lines and neutral are very much disturbed by the unbalanced load.

Diagrams of the connections necessary for the testing of ampere-

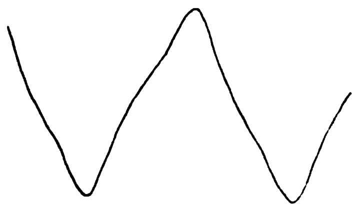


Connections.

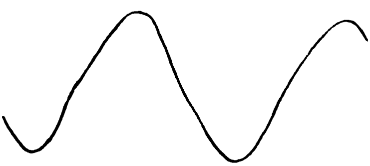
No. 3.—Pressure Wave on A D.



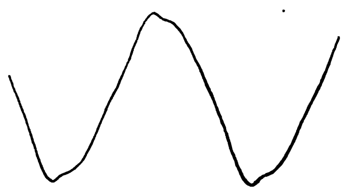
No. 1.—Open-circuit Wave on A B.



No. 4.—Pressure Wave on B D.



No. 2.—Wave on A B when Loaded.



No. 5.—Pressure Wave on C D.

FIG. 14.

TABLE I.

Voltmeter connected to—	Volts, R.M.S.	
	Machine on Open Circuit.	Machine Loaded.
A B	112·0	100·5
A C	112·0	98·0
B C	112·0	117·5
A D	65·0	54·5
B D	65·0	65·5
C D	64·5	63·0

hour meters, direct-current watt-hour meters, and alternating-current watt-hour meters, are given in Figs. 15 to 18.

The testing of continuous-current meters presents no special difficulties, and the results of the tests carried out by testing authorities are rarely disputed.

With alternating-current meters, however, when the accuracy is in dispute the person responsible for the testing is immediately assailed

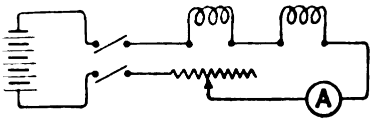


FIG. 15.

with questions relating to the method employed. These questions usually refer to the voltage, frequency, power factor, and wave-form of the testing circuits, and in the case of a polyphase meter, to whether it was tested on a single-phase or a multi-phase circuit.

Thus, whilst the accuracy of a direct-current meter is accepted, usually without question, that of an alternating-current meter is looked upon with a certain amount of doubt or suspicion.

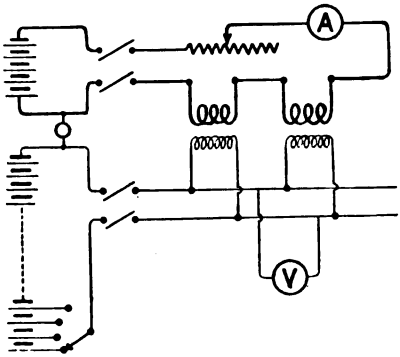


FIG. 16.

Results of some Tests on Alternating-current Induction Meters.—The tests described in the following section were carried out by the authors on a number of meters of the induction type supplied by different manufacturers. Most of the tests relate to the effects of wave-form and to the methods of testing polyphase meters.

The voltage and the frequency of the testing circuit could be maintained constant within about one-half of 1 per cent., and it was found by some preliminary tests that these variations could produce no measurable errors in the meters—assuming, of course, that the watts on the meters were kept quite constant by regulation.

Effect of Wave-form.—When all other considerations for the inconsistencies in the results obtained when testing induction type meters fail in explanation, the inconsistencies are attributed to wave-form, mainly, perhaps, because the effect of change of wave-form is not easy to predict, and is generally unknown.

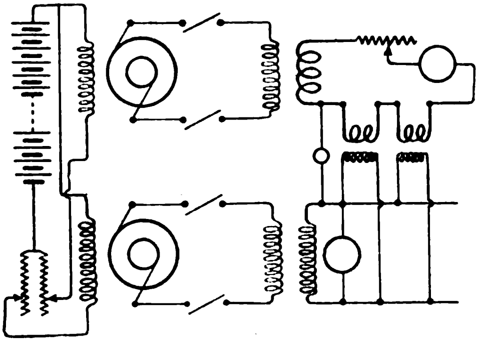


FIG. 17.

That alteration of the shape of the alternating-current wave does affect the accuracy of the registration of induction meters is shown by the results given below.

The small amount of information available relating to the effects

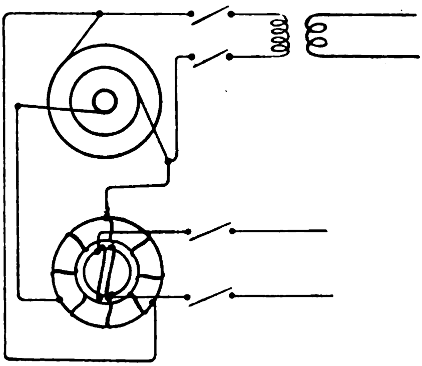


FIG. 18.

of variation of wave-form, is possibly due in some considerable measure to the lack of suitable apparatus for producing and examining waves of different shapes.

There are various methods of changing the shape of the wave given by a particular alternator, but it not infrequently happens that, whilst it is a comparatively easy matter to produce the change on the open-

circuit wave of the machine, the new wave shape is not maintained when the machine is put on load.

A peaked wave may be obtained from a machine giving normally a sine wave, by using a transformer and connecting it to the machine with a resistance in series with the primary circuit. If the iron of the transformer is worked near its saturation point a very peaked wave is obtained from the secondary. Any appreciable load on the secondary, however, restores the secondary wave closely in shape to that of the machine if regulation is effected by means of the resistance in the primary.

For the purpose of the tests given in this paper experiments were made adopting the above method, and in order still further to change the wave, the secondary of the transformer used was connected in series with the alternator provided with the movable stator (in set previously described), the primary of the transformer being connected to the fixed stator machine in series with a resistance. By altering the relative phases of the wave from the secondary of the transformer and the alternator some most extraordinary shapes were obtained. It was found, however, that the circuit was a useless one for the purpose for which it was required, as the shape of the wave could not be maintained when load was put on.

Resort was then had to the method adopted at the National Bureau of Standards, Washington. By driving a second alternator at three times the frequency of the first, and connecting the armatures of the two machines in series, the third harmonic was superposed on the fundamental obtained from the movable stator machine. By this means the amplitude and phase of the harmonic could be altered relatively to the fundamental, and the wave was easily maintained when the machines were loaded. The higher frequency alternating current was obtained from a small 1-H.P. inductor-type alternator, driven at the correct speed by a chain and sprocket-wheels from the twin alternator set producing the lower frequency current. The waves from the machines are not quite sine waves, and the resultant waves indicate the presence of harmonics higher than the third.

A number of waves were tried, and note taken of the composition or mixing, and it was then found to be quite a simple matter to reproduce any wave previously used.

In order to avoid delay and possible alteration of physical conditions in the meters, the circuits were so arranged that by means of a change-over switch the change from the fundamental to the mixed wave could be quickly made, and by means of a second change-over switch the harmonic wave could be reversed so as to produce a peaked or a dimpled wave. The oscillograph used for observing the waves was kept continuously in circuit, so that there was never any doubt as to the shape of the pressure and current waves of the circuit. A lamp load was used, and the shape of the current wave was the same as that of the pressure wave in all cases where the power factor of the circuit was unity.

The results of the tests are given in Table II., and reproductions

from photographs of the various waves, together with the proportion of harmonic to fundamental, are shown in Fig. 19. The percentage errors in the table represent the percentage deviation in the speed of the meter when tested with the various waves, from the speed obtained when tested with wave No. 1, which represents the fundamental. After testing with each of the mixed waves a check test was made with the fundamental, and the results for this wave always showed extremely close agreement.

TABLE II.

Table showing the Percentage Deviation in the Speeds of the Meters when Tested with the various Waves, from the Speed when Tested with Wave No. 1.

Wave No.	Power Factor.	Percentage Deviation in Speed of Meters from Speeds with Wave No. 1.			
		Meter A.	Meter B.	Meter C.	Meter D.
1	Unity	—	—	—	—
2	Unity	—	0·7 *s*	1·0 *s*	1·9 *s*
2*a*	Unity	0·1 *s*	0·3 *s*	1·3 *s*	0·8 *s*
3	Unity	0·9 *s*	1·0 *s*	3·5 *s*	6·6 *s*
3*a*	Unity	1·1 *s*	0·3 *s*	3·5 *s*	2·0 *s*
4	Unity	1·9 *s*	1·7 *s*	7·5 *s*	11·7 *s*
4*a*	Unity	2·1 *s*	1·0 *s*	7·4 *s*	7·3 *s*
5	Unity	6·6 *s*	4·4 *s*	21·6 *s*	27·0 *s*
5*a*	Unity	6·2 *s*	4·1 *s*	20·3 *s*	23·3 *s*
6	Unity	—	—	—	5·4 *s*
6*a*	Unity	—	—	—	3·4 *s*
7	0·8	—	—	—	0·1
7*a*	0·8	—	—	—	1·9 *s*

s = slow. *f* = fast.

Nos. 6 and 6*a* are approximately of the same composition as 3 and 3*a*, with the phase of the harmonic altered.

No. 7 and 7*a* are approximately of the same composition as 3 and 3*a*, but with inductive load.

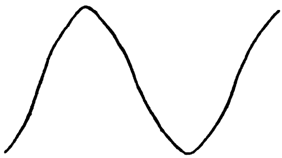
It will be noted from the results that the accuracy of some makes of meters is more seriously affected by change of wave-form than the accuracy of others, but all are seriously affected with some of the waves used. The waves used are no doubt in some cases abnormal, but an attempt was made to obtain measurable errors, and this, it is seen, was quite an easy matter.

The waves numbered *2a*, *3a*, etc., are as nearly as possible of the same composition as those numbered 2, 3, etc., respectively, but with the harmonic waves reversed, or changed in phase by 180°.

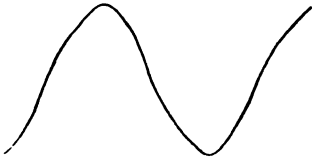
The errors of two of the meters, B and D, vary with the phase of the harmonic (relative to the phase of the fundamental) as well as the amplitude, and it will be noted that they register slower with a peaked wave than with a dimpled wave. Meters A and C register approximately the same on either form of wave. It may further be noted that when the power factor of the circuit is unity the errors increase, in all meters, as the proportion of the harmonic to the fundamental is increased, and that the meters register slower.

Meter D, which appears to be the most sensitive (of the meters tested) to changes in wave-form, was tested with waves of approximately the same composition as waves Nos. 3 and *3a*, but with the phase of the harmonic wave intermediate between 3 and *3a*. The results are given under waves 6 and *6a*, but the actual waves are not reproduced. The two errors of the meter on these two waves are more nearly alike, and should be compared with the errors of this meter on waves 3 and *3a*. The same meter (D) was also tested with waves having approximately the same composition as Nos. 3 and *3a*, but with an inductive load at a power factor of about 0·8. The results are given under waves 7 and *7a*, and it will be noted that the errors come out comparatively small. It must be mentioned, however, that although the composition of the wave was arranged to be approximately the same as wave No. 3, the actual resulting wave on the inductive load was different in shape from that of No. 3, and further, the current wave differed in shape from the pressure wave. These waves were

Wave No.	Volts, R.M.S. Fundamental.	Volts, R.M.S. Harmonic.	Volts, R.M.S. Resultant.
1	100	—	100
2	112	36	100
2A	113	40	100
3	109	50	100
3A	111	58	100
4	105	68	100
4A	107	76	100
5	92	112	100
5A	92	118	100

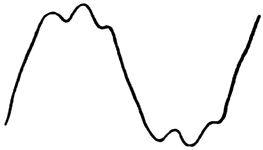


Open-circuit Wave of No. 1.



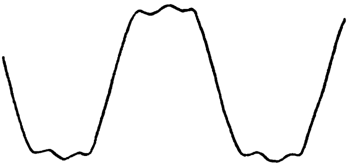
No. 1.—$V = 100$.

No. 2.—$V = 100$, $V_F = 112$, $V_H = 36$.

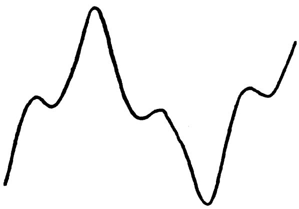


No. 2A.—$V = 100$, $V_F = 113$, $V_H = 40$.

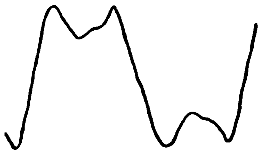
No. 3.—$V = 100$, $V_F = 109$, $V_H = 50$.



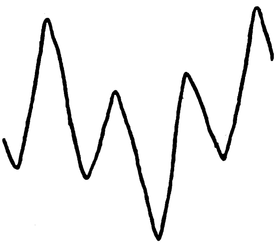
No. 3A.—$V = 100$, $V_F = 111$, $V_H = 58$.



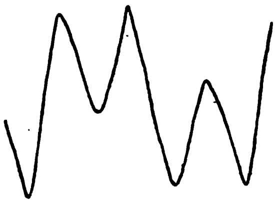
No. 4.—$V = 100$, $V_F = 105$, $V_H = 68$.



No. 4A.—$V = 100$, $V_F = 107$, $V_H = 76$.



No. 5.—$V = 100$, $V_F = 92$, $V_H = 112$.



No. 5A.—$V = 100$, $V_F = 92$, $V_H = 118$.

FIG. 19.

V = R.M.S. of Resultant Voltage.
V_F = R.M.S. of Fundamental Voltage.
V = R.M.S. of Harmonic Voltage.

not photographed, but it may be mentioned that they appeared even more abnormal than No. 3.

The authors are not prepared at present to advance any theory for these effects of changes in wave-form, but several possible causes suggest themselves, such as :—

Alterations in the nature of the rotating or shifting magnetic fields.

Effects on the fluxes in the cores by changes in the eddy currents and hysteresis of the iron.

Effects on the quadrature adjustments.

Effects of frequency; it will be noted that as more of the harmonic wave is added, the resultant wave approaches more nearly to the triple-frequency wave of the harmonic.

From the results it would appear that there is a limit to the amount of variation of the wave-form of the circuit on which induction meters are used, if the errors of the meters are to be kept within specified limits.

The case is not adequately met by testing the meters on a wave-form the same as that with which they will eventually be used, because the wave-form of a generator is usually somewhat modified by the load.

A meter of the dynamometer type was also tested, and it was found that the errors with the various waves were so small as to come within the limits of errors of observation. This result was anticipated, as the standard indicating wattmeter used for the tests was a Duddell-Mather instrument of the dynamometer type.

Testing Polyphase Meters.—The 2-meter method of measuring the energy in a 3-phase 3-wire circuit has been previously referred to as constituting the best standard practice, and it is the only one dealt with in this section.

All the various tests described below have been made on the twin, or combination, type of meter, with a common set of integrating dials.

If these polyphase meters were perfect, their registrations would represent the total energy of the circuit, independently of the nature of the load, whether balanced or unbalanced, and of the value of the power factor. In order that the meters may register accurately, each of the two single-phase elements of which such meters are composed, must be unaffected by the alternating fluxes set up in the other element. It must be remembered that when two single-phase meters are used for measuring the energy in a 3-phase 3-wire circuit, the phase difference between current and voltage is not the same for both meters. Thus in a polyphase meter, used on a 3-phase circuit of unity power factor, each element is connected to a circuit of power factor 0·866, but in one element the current through the series coil is leading the voltage by 30°, while in the second the current is lagging behind the voltage by 30°.

Fig. 20 shows how the power factor of a balanced 3-phase load affects the ratio of the watts on the two meters, and also how the

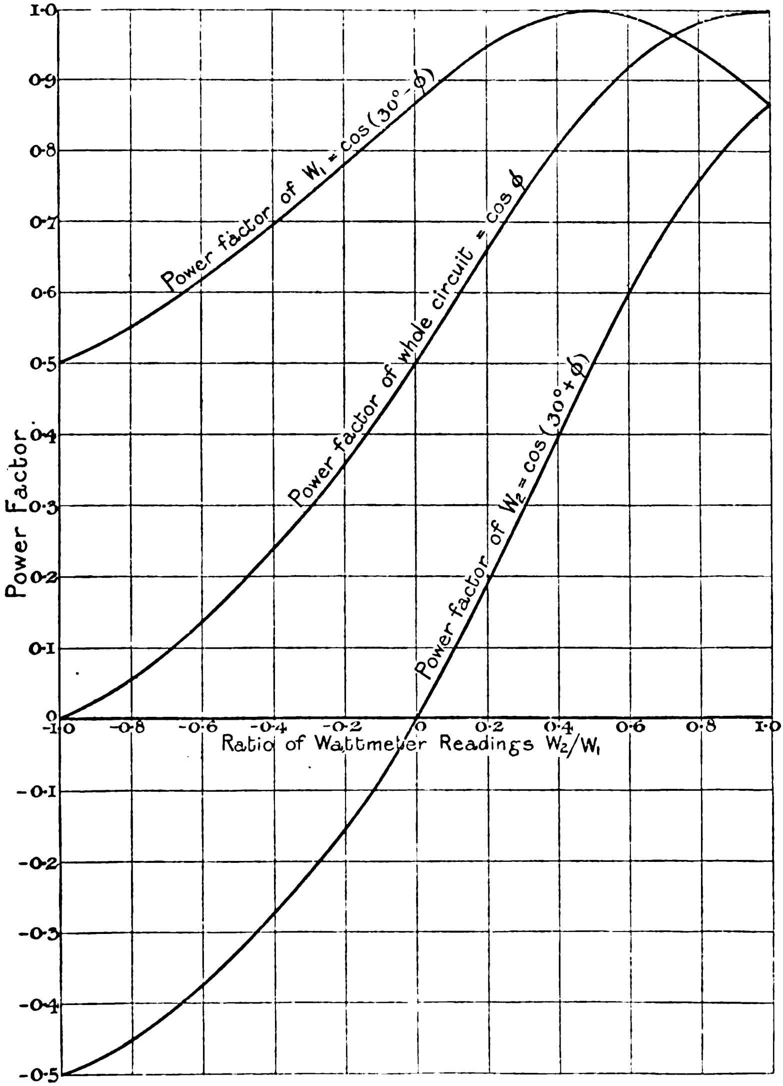


FIG. 20.

equivalent power factor for each meter is affected by the power factor of the load.

In this connection it may be noted that the power factor of one of

the meter circuits may have a very low, or even a negative value, and under these conditions the meter may have a rather large error, but as it only integrates a correspondingly small proportion of the total power in the circuit, the accuracy of the 2-meter combination may still be very good.

Now, since two single-phase meters may be used to measure the energy, it should be possible to test a polyphase meter by testing each element separately as a single-phase meter, and this method could certainly be adopted if there were no interaction between the two elements. Unfortunately, however, there is always the possibility that

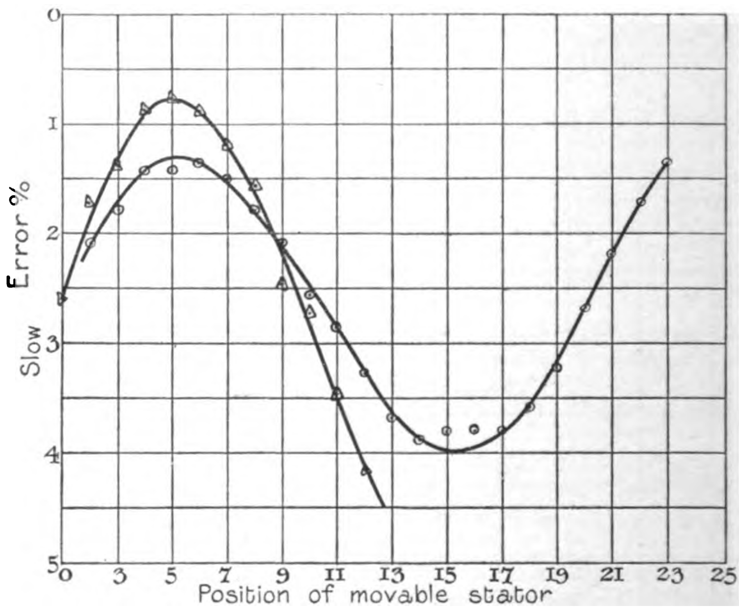


FIG. 21.

the registrations of either of the two elements will not be unaffected by variations due to load on the other.

The testing of polyphase meters therefore presents considerable difficulties, and it is, in the authors' opinion, very doubtful whether it is possible to test a polyphase meter so that the result may be relied on to the same degree of accuracy as is the case with a single-phase meter. If the meter cannot be tested as two separate, single-phase meters, it is doubtful whether it can possibly be a true polyphase meter.

With the object of clearing up this point, a number of induction type polyphase meters were tested on a 3-phase circuit, and on different arrangements of single-phase circuits. The results obtained

showed considerable variation in the accuracy of the meters when tested on the various circuits.

Tests for Interaction between the Elements of Polyphase Meters.— Interaction between the fluxes of the two elements was not at first suspected, but it was afterwards found to exist from the fact that the speed of the meter was appreciably affected by the relative phases of the fluxes of the two elements.

In order to determine the effect on the speed of the meter, caused by altering the relative phases of the loads on the two elements, each element was supplied separately with a definite load, one from each of the two machines described on page 32, Fig. 12, and, keeping the load on each element constant, a series of observations was taken with the movable stator of the one machine in a number of successive positions. The results for two meters of the two-disc type are shown by the curves Fig. 21.

It is to be noted that the maximum and minimum speeds of the meter occur at a difference of phase of 180° between the loads. To verify this, the movable stator of the machine was adjusted until the maximum speed of the meter was observed. The connections to the machine were then reversed. This had the effect of bringing the speed down to its minimum. The connections to the second machine were then also reversed, and the speed again rose to the maximum, thus verifying the fact that the maximum and minimum speeds were obtained by an alteration of the phase of the power on one element by 180°.

The fact that the change of phase difference producing maximum effect was 180° led to the conclusion that there was probably magnetic interaction between the two elements.

In making subsequent tests on other meters for this magnetic interaction it was found unnecessary to determine curves as in Fig. 21. The maximum and minimum speeds for a meter were equally well determined by connecting the two current coils in series, and the two pressure coils in parallel with each other respectively, and using one single-phase alternating-current supply. After noting the speed for a particular load, the connections to the current and pressure coils of one element of the meter were reversed, and the speed again noted with the same load.

For the purpose of the authors' investigation, one of the manufacturers kindly made up a special two-disc meter, so arranged that the space between the two elements could be altered at will.

With this it was found that when the elements were separated as far as possible, the effect of interaction was about one-half of what it was when the elements were in their normal position.

Some effects of this interaction on the registrations of different makes of meters are shown in Tables III. to VI.

It may be mentioned that only one of the meters tested was free from this defect of interaction; but as it was found to be present in other meters of the same type and make, it appears that even the meters of this firm cannot be said to be free from the defect.

TABLE III.

The Vectors in Tables III. to VI. indicate the Manner in which the Coils of the Elements of the Meters are Excited.

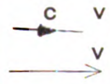
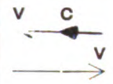
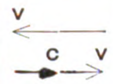
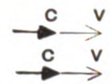
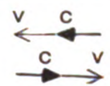
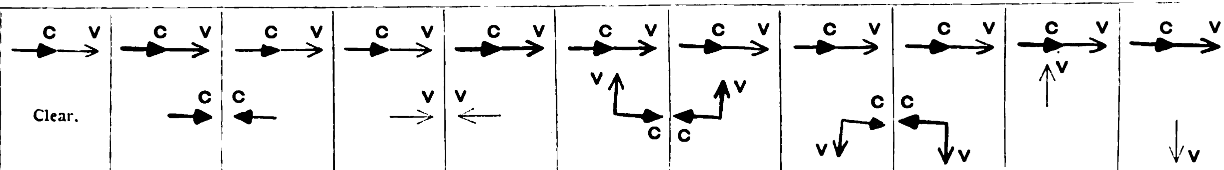
Condition of Element No. 1 ... ... Condition of Element No. 2								
Meter.	Load.	Power Factor.	Error Per Cent.	Error Per Cent.	Error Per Cent.	Error Per Cent.	Error Per Cent.	Error Per Cent.
B	Full	Unity	0·7 fast	3·3 slow	1·2 fast	0·3 slow	0·2 fast	2·4 slow
	$\frac{3}{4}$	Unity	0·7 ,,	27 ,,	1·6 ,,	O.K.	0·6 ,,	2·0 ,,
	$\frac{1}{2}$	Unity	0·9 ,,	2·7 ,,	2·0 ,,	O.K.	1·0 ,,	1·7 ,,
	$\frac{1}{4}$	Unity	1·3 ,,	2·7 ,,	2·1 ,,	0·3 fast	1·4 ,,	1·6 ,,
	$\frac{1}{10}$	Unity	2·1 ,,	2·3 ,,	3·2 ,,	0·7 ,,	2·0 ,,	1·4 ,,
F	Full	Unity	6·2 ,,	2·9 fast	5·4 ,,	2·8 slow	4·8 ,,	0·6 ,,
	$\frac{2}{5}$	Unity	6·5 ,,	3·3 ,,	3·9 ,,	5·2 ,,	4·4 ,,	1·2 ,,
	$\frac{1}{5}$	Unity	8·1 ,,	3·2 ,,	3·3 ,,	6·3 ,,	4·2 ,,	1·3 ,,
	$\frac{1}{10}$	Unity	8·2 ,,	4·0 ,,	3·3 ,,	6·0 ,,	4·5 ,,	2·0 ,,
G (Two discs and differential gear.)	$\frac{3}{4}$	Unity	1·4 ,,	1·4 ,,	0·6 ,,	5·6 fast	No. 1 Element. 1·9 fast No. 2 Element. 0·9 fast	No. 1 Element. 1·4 fast No. 2 Element. 6·2 fast

TABLE IV.



Meter.	Load.	Error Per Cent.	Error Per Cent.	Error Per Cent.	Error Per Cent.	Error Per Cent.	Error Per Cent.	Error Per Cent.	Error Per Cent.	Error Per Cent.	Error Per Cent.	Error Per Cent.
Condition of Element No. 2 ...		Clear.										
A	Full	5·6 fast	2·2 fast	5·2 fast	3·7 fast	3·3 fast	2·2 fast	0·7 slow	0·2 slow	2·6 fast	2·7 fast	3·3 fast
A	½	5·1 „	2·6 „	5·6 „	3·0 „	2·4 „	4·1 „	0·8 „	0·5 „	4·6 „	1·3 „	2·7 „
A	¼	2·7 „	0·7 „	4·0 „	1·7 „	1·8 „	3·8 „	2·5 „	2·0 „	4·8 „	0·9 „	1·7 „
E	—	1·2 slow	0·7 „	4·1 slow	9·9 slow	7·5 slow	4·5 slow	8·0 „	O.K.	7·1 slow	5·3 slow	2·9 slow

TABLE V.

Condition of Element No. 1 ... Condition of Element No. 2 ...			V → C →	V → ← C	C → V →	← C V →
Meter.	Load.	Power-factor.	—	—	—	—
B	Full	Unity	Disc runs forward 1 rev. in 192 secs.	Disc runs backward 1 rev. in 215·6 secs.	Disc runs forward 1 rev. in 133 secs.	Disc runs backward 1 rev. in 116 secs.
F	Full	Unity	Disc runs forward 1 rev. in 173 secs.	Slight creep backward	Slight creep backward	Disc runs backward 1 rev. in 360 secs.
A	Full	Unity	Tendency to run backward	Tendency to run forward	Tendency to run backward	Tendency to run forward
G	$\frac{3}{4}$	Unity	Left disc only creeps forward	Left disc only creeps forward	Right disc only creeps backward	Right disc only creeps backward

TABLE VI.

Test for Interaction between the Elements and an Aron 3-phase Clock Meter.

	Shunts of both Elements Excited in Parallel.	Shunts Excited at 120° (on Lines).	Left Element Shunt and Series Coils Dead.	Current only on Left Element, in Reverse Direction of Right Element.	Current Lags 90° in Left Element, and Volts in Phase in both Elements.	Current Leads 90° in Left Element, and Volts in Phase in both Elements.	Current only on Left Element, in same Direction as Right Element.
	Error per Cent.	Error per Cent.	Error per Cent.	Error per Cent.	Error per Cent.	Error per Cent.	Error per Cent.
Left element loaded ...	1·0 slow	1·6 slow	—	—	—	—	—
Right element loaded ...	0·4 ,,	0·3 ,,	0·6 slow	O.K.	1·7 slow	1·5 slow	1·5 slow
Both elements loaded ...	2·0 ,,	1·5 ,,	—	—	—	—	—

Extra Braking Torque in Induction Polyphase Meters when both Elements are Loaded.—The driving fluxes of the coils in meters of the induction type also act as braking fluxes. The braking flux is thus due partly to the load, as well as to the permanent magnet; this results in the braking torque not being simply proportional to the speed, but varying with the load.

When testing one element only of the meter, it is essential to have the pressure coil of the second element excited, because the flux produced thereby acts as a brake flux on the disc, and in actual use both the pressure coils of the meter are excited.

Now, if a speed of n revolutions per minute is obtained when one element only is loaded, a speed of $2n$ revs. per minute would be obtained if twice the driving torque were applied without altering the total brake flux. If an additional load equal to that already acting on one element of the meter be applied to the second element, the driving torque will be practically doubled; but the addition of the current flux in the second element will also add to the brake-field. Owing to the increased braking flux, the braking torque will rise to double its original value, at a speed which is less than twice the original speed of the meter.

If equal speeds are obtained with equal loads on each element separately, it follows that when equal loads are applied to both elements together, the speed of the meter will be less than twice the speed obtained with either element separately. Or, when both elements are loaded, the speed is less than would be obtained by calculation from the speeds of each element taken separately on their respective loads.

The above effect is most marked at the higher loads. It may, however, in some cases be neutralised by the effect of the magnetic interaction previously referred to, and the speed of the meter in such a case may be even higher proportionately when both elements are loaded than when only one is loaded.

From a testing point of view, especially with meters of large capacity, it is of great importance to be able to test with single-phase current. To have to set up a double 3-phase circuit for the current and pressure would be most inconvenient, and, moreover, as has been previously stated, if the meter cannot be tested as a single-phase one, it is doubtful whether it can possibly be a true polyphase meter.

When series transformers are used with the meters, the meters are usually of a small enough capacity to test directly as 3-phase meters, and the ratios of the series transformers at the various loads can be determined separately; but even this method is not satisfactory on account of the phase error in the transformers, which it is difficult to measure, and which varies with the load.

Shunt transformers can usually be tested for ratio and the necessary corrections applied to the calibration of the meter, because they will, as a rule, be used at, or near, one stated voltage, and the phase error in a good shunt transformer is negligibly small if it is not overloaded.

In conclusion, the authors regret that the investigations on the effects

of wave-form, etc., are not more complete, but while the results given are comparatively few, the number of tests carried out in order to obtain and verify them has been very large. For example, much time was spent in trying to reconcile, by experiments, the inconsistent results obtained in the tests on polyphase meters, before it was even suspected that there was the appreciable magnetic interaction afterwards discovered. The authors have decided to continue the investigations, and to deal also with meters when used with current and pressure transformers.

The authors wish to make acknowledgment to the Principal, and the Committee of the Manchester School of Technology, and to the Chief Electrical Engineer of the Manchester Electricity Department, Mr. S. L. Pearce, for facilities for carrying out the tests detailed in the paper. To Professor Schwartz and Mr. C. F. Smith for reading through the manuscript and offering many suggestions. To Messrs. The British Westinghouse Company, The Electrical Company, Siemens Bros., Ferranti Ltd., and The Aron Meter Company, for the loan of meters; and to Messrs. P. Kemp, J. Davies, G. W. Wadsworth, O. Howarth, A. M. Doig, and F. H. Williams, for assistance in the experimental work.

Discussion.

Mr. S. H. Holden: I have studied this paper with very great interest. It contains a very large amount of useful matter, and tempts discussion at almost every point. I am very much interested in the work on the effect of wave-form upon the accuracy of alternating-current meters. It is quite a usual thing for purchasers of meters to specify that they are to be unaffected by variations in wave-form, but they do not give the least hint as to what variations are to be looked for or how the meters are going to be tested to see whether they conform to the specification. Further, the British Standard Specification does not give any assistance in this direction, and I hope that the work which the authors have done may lead to greater precision in this department. With regard to shunts to mercury meters, the authors say that these may have certain possible advantages. I think it would be quite fair to say that those are positive advantages, as for the most part there is no doubt about them. Shunted mercury meters have been in use to my knowledge for fourteen or fifteen years at least, and I have known of very many cases where meters have been tested after seven or eight years' use and are still quite accurate. The resistance of the mercury in a meter is a very small proportion of the total: the actual resistance is mainly in the coils and the connections, and even if it did vary, and vary very considerably—though I do not think it does—it would have very little effect on the accuracy of the meter. A mercury meter to carry 1,000 amperes without a shunt would be quite a big thing, more like a gas meter than an electricity meter. I should like to ask whether the experiments upon which the authors based their opinions were conducted upon the latest type of mercury watt- Mr. Holden.

Mr. Holden.

hour meter. So far as I know, there is only one mercury watt-hour meter on the English market, and therefore, of course, their remarks must be confined to that. My impression is that the authors' experiments were conducted on some rather early specimens, and I know that the meter has been very considerably improved since that date. Perhaps it may not be out of place to say that, in spite of the disapproval expressed, the mercury watt-hour meter has been approved as a consumer's meter by the Board of Trade. With regard to tramcar meters, the authors do not think there is one on the market which will withstand the severe conditions for any length of time. I do not quite know what they mean by a "length of time." Is it one year, two years, or twenty years? I do know that several makers are prepared to guarantee to keep their tramcar meters in good and accurate working order any time up to twenty years at a charge of 3s. 3d. per meter per annum, and that does not look as if they were very bad. A short time ago I had a new tramcar meter standardised in the test-room, and I sent it up to a tram depôt and asked them to put it on a car in series with an old meter. The old meter, as I found out afterwards, had been working for about twelve months, but I did not select the meter or the car. The two meters were run in series for about three weeks and are still running. There has always been a difference of about 2 per cent. between them; one, I think, is 1 per cent. fast, and the other 1 per cent. slow. That 2 per cent. difference has been maintained quite constantly and is shown perfectly regularly on every daily reading, so that the old meter is just as accurate as the new one. Being only a manufacturer of meters I must not, I suppose, set up my opinion against that of the authors as to the suitability of tramcar meters, but I should like to read an extract from a letter which has been written to me by Mr. Baker, of the Birmingham Corporation Tramways. It incidentally deals with the doubt which is implied in the paper as to the usefulness of tramcar meters even if they are accurate. Mr. Baker says, "With reference to our conversation I have pleasure in stating that we have been using your car meters since December, 1909, and that every car we have has a meter fitted in it, that is 300 in all. The results have been extremely satisfactory. Our accounts show that this year we shall have an actual cash saving of £5,000, notwithstanding the fact that we have run 250,000 car-miles more than the corresponding period last year. I may say that during this period there has been a complete absence of breakdown, and the repairs have been very slight"—that, I may say, refers to the meters. "The saving in current, however, is not the whole story. We find economies accruing from use of meters on all sides, particularly with regard to brake-shoes; in this item alone our consumption will be 33 per cent. less than last year. There is also a considerable saving in wheel tyres and other equipment."

Mr. Melsom.

Mr. S. W. Melsom: There are one or two points in the paper which I think are extremely valuable. One is the effect of the temperature and heating in direct-current meters. The temperature co-

efficient in meters is a thing which is usually ignored. It is, however, likely to lead to serious errors if, as is often the case, a meter is calibrated at the maker's works at a temperature of 15° C. and then erected in a station or some large supply place where the temperature is probably about 25° C. That is in the case of a motor meter of course. I wonder why makers of motor meters do not affix to the meter a red label stating that "This meter has a temperature coefficient, and this is the temperature to which it is standardised." I think that would help even the manufacturers themselves. Another Mr. Melsom.

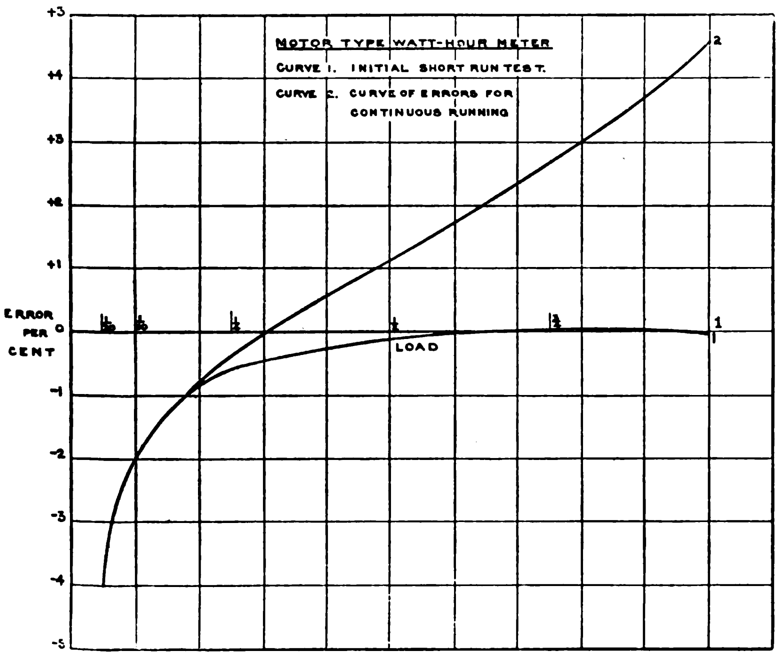


FIG. A.

point which the authors have dealt with, not quite so fully, is with regard to the heating in the meters themselves. This is one of the most serious sources of error that we find in large motor meters at the National Physical Laboratory. The meters heat up very largely owing to the heating in their own coils, and so increase in rate. The authors seem to think that the heating is not serious unless it is accompanied by bad contacts; it can, however, be very serious indeed without bad contacts. Fig. A shows a curve that was obtained with a large-sized watt-hour meter of a type which is very largely in use for traction and for other purposes at the present day. The lower curve gives the results which were obtained when the meter was tested by short run

Mr. Melsom.

tests, of two minutes apiece, when it was cold, and the upper curve shows the errors of the meter when it is running continuously at any load. It will be seen that at full load there is a difference, owing to heating, amounting to about 4·6 per cent.; but that, I should explain, is not the worst of that particular size of meter that one comes across; it is absolutely the best, and, moreover, there is in this case no question whatever of any heating due to bad contacts. That curve also shows the method which we use at the National Physical Laboratory for testing a direct-current meter. Take, in the first place, a curve when the meter is cold. It will be seen that in this case the meter is very accurate from one-quarter load up to full load. Then it is run on full load until it attains, or nearly attains, its maximum heating, which in this case was about five hours. Then, of course, the other points on curve No. 2 can be computed, thus giving the accuracy for con-

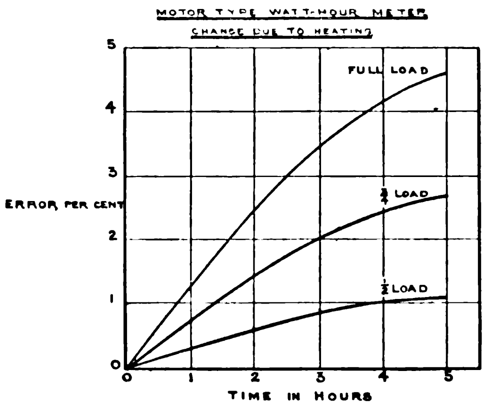


Fig. B.

tinuous running at any load. In Fig. B is shown the time which the meter takes to attain its full heating, or somewhere near it. Those errors, of course, are not present in all motor watt-hour meters. That is, perhaps, a very bad example; but still we have to look for the same effects to a very fair extent in practically all types of watt-hour meters. Even in little mercury type ampere-hour meters we often get a variation of something like 2 per cent. owing to the heating inside the meter when it is run at full load.

There are a number of points in the paper which one might deal with, but I will confine myself to remarking on the curve the authors have shown as being characteristic for commutator ampere-hour meters. I was very interested in that curve, because the results, though they are not very good, are somewhat better than any we have been able to obtain, though we have not tested very many meters of that type. In Fig. C are shown two curves which were obtained with the

mean of four meters of this type. The first was obtained when the meters were cold, and the second after they had been run for several hours at full load and then re-tested after an interval of two days. The first curve is somewhat better than the authors' curve, but the second one is very much worse; the error at one-quarter load is somewhat like 6 per cent., and the meters have quite obviously changed in calibration. I shall be interested to learn if the authors made any further tests after their meters had been in use for some time, and, if so, what results they obtained. Mr. Melsom.

There is one other point to which I should like to refer, and that is with reference to the relative loss in watts in mercury meters and watt-

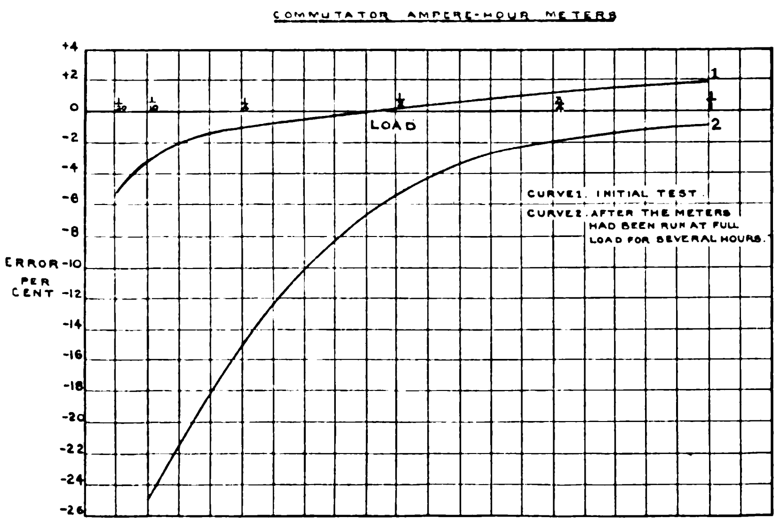


FIG. C.

hour meters. I am not here as an apostle of any particular type of meter, but I think that that comparison as to watt losses is very unfair. To begin with, the authors state that the shunt losses in a 200-volt watt-hour meter would not exceed 4 watts. In the Engineering Standards Committee Specification the maximum allowed is 4 watts per 100 volts; and, looking up records, the average loss in the shunt circuit of 200-volt watt-hour meters is found to be something like 6 watts. But the main objection I have to that comparison is that the authors have only taken into account one particular part of the losses in the meters, whereas for a fair basis of comparison the whole of the losses in both types of meter should be taken. As a matter of fact, the watts lost in the current circuit of watt-hour meters of small size are about three times as large as in mercury type ampere-hour meters of the same size.

Mr. Garton.

Mr. E. GARTON: There are one or two points I should like to touch upon. On page 7 where the authors say, "This design is only permissible on the assumption that the copper and mercury used are both chemically pure," they seem to be in doubt as to whether pure copper and pure mercury are obtainable. I am glad to be in a position to inform them that this is quite possible, and I have been able to obtain both metals chemically pure for the last four or five years, and have used them in meters with very good results. I think, however, of the two metals it is most essential to have the copper pure, as should there be any impurities in the copper they are likely to amalgamate with the mercury and tend to stop the meter, this being far more serious than oxidation of the mercury. I have had several opportunities of examining the armatures referred to that have been in meters from three to five years, and in every case I have found even the original tool marks showing, proving that the amalgamation had not proceeded any further than when they were first put into the meters. I think there are a good many meter users who can bear out this statement, as there have been several of these meters opened up at different times by station engineers, and the armatures, so far as I am aware, have in every case been found to be in perfect condition.

On page 17 the authors say, "The great objections to the induction type are the small driving torque and the variation in accuracy with varying wave-form." The torque of an induction meter, of course, is very much less than that of the dynamometer type, but the weight of the moving element of the dynamometer type is very much greater than that of the induction meter, and if the ratio of torque to weight is taken into consideration it will be found that there is little difference between them. The weight of the moving element of the dynamometer type is about 100 grammes, as compared with 25 grammes in the induction meter, and the torque 25 centigrammes as compared with 5 centigrammes respectively. These ratios work out at 0·25 for the dynamometer meter and 0·2 for the induction meter. Now if these figures are divided by the losses of the respective meters an idea will be obtained of the efficiency of the two meters; taking the losses of the dynamometer type as 10 watts and those of the induction type as 2 watts, a ratio of 0·025 to 0·1 is obtained in favour of the induction type, proving the induction type to be by far the most efficient.

On page 20 the authors consider that by shunting the current coils of a dynamometer with a non-inductive shunt it should be possible to compensate for the inductive loads. This is quite correct, and has been used in the United States for a good many years. The current taken by the shunt in the Thomson meter is approximately one-tenth of that taken by the meter, so if the torque is to remain the same, it is necessary to put more turns, and therefore more copper, into the coils of the meter than would otherwise be necessary, which would increase the cost of the meter. I mention this as the authors lay stress on the question of cost. They seem to think it is quite reasonable to increase the cost of meters, but I do not think many buyers would agree; but the

manufacturers, I am sure, would be quite prepared to make even a more accurate meter than that made to-day if buyers were prepared to pay a higher price. Taking the case of an induction meter, the accuracy can be improved by increasing the torque and by lowering the speed. Now directly either of these factors is altered to improve matters, the cost of the meter materially increases, it being necessary to increase the size of the magnets or to add more, and at the same time increase the size of the meter. I think this step would hardly be advisable. I am very glad the authors have brought up the subject of the proper use of polyphase meters. I agree with them that, on a polyphase circuit, it is absolutely necessary to use a polyphase meter or the equivalent. I have tested a good many polyphase circuits, but so far have not found one that was actually balanced. The authors have referred to the question of shunts on mercury meters on page 16 and seem to think that shunts are undesirable because the resistance of the bath may change, and cause considerable errors. I cannot agree that this is the case. I have made tests on a meter to-day, and find that the voltage drop on the bath itself was only 2 millivolts, and that the leads in series with the bath amounted to 30 millivolts. Now, even if the resistance of the bath increases 100 per cent., which I do not think likely to happen under ordinary circumstances, the total drop will only increase from 32 to 34 millivolts, causing an error of only about 6 per cent., so it does not appear to be a very serious matter. Mr. Garton.

Mr. L. W. WILD: The most interesting part of this instructive paper to me is with regard to the test of the effect of wave-form. From a cursory inspection of these results we might be tempted to conclude that the determining factor giving rise to these errors is the amplitude of the harmonics, the phase of the harmonics being of comparatively small importance. A year and a half ago when I made a similar series of tests I rather expected to find something of the same sort; I expected to find that it was the amplitude of the harmonics which was going to cause the errors, and I expected that the meters would all run too fast. Instead of this, however, I found that some meters ran fast and some meters ran slow on a peaked wave, but in every case on a flat wave the error was in exactly the opposite direction to what it was on a peaked wave. These tests seem to indicate—if any of these waves can be called flat—that errors are in the same direction on a flat or peak; but when we look at the nearest approach to a flat wave, No. 2 (*a*), it is nothing like a smooth wave—it has chimney-pots on the top, which probably give it some of the attributes of a peaky wave. I think if the authors had a smooth flat wave without any architectural features, they would perhaps have found what I did, that the error would be in the opposite direction, in some cases at any rate. I rather regret the authors did not include the form factors of these waves; they would have been very useful for comparative purposes. It is hardly possible to work them out from such small diagrams. I am very glad they have made this very thorough investigation into the interactions in polyphase meters. My recent practice in testing polyphase meters has been to test on a Mr. Wild.

Mr. Wild. single phase with the current coils in series and the shunt coils in parallel, and then to reverse connections and make a second test. In every meter I have tested in that way I have found a considerable difference between the two tests—2 or 3 per cent. is quite common—and what I have done is to take the mean between the two, pointing out that there is this difference. As far as I can see from these figures here, we are as likely to arrive at the truth that way, on the whole, just as nearly as if we tested on a 3-phase circuit. In testing on a 3-phase circuit, there are two ways of connecting up the meter. The top element may be leading and the bottom lagging, or *vice versâ*, and if the test is made one way and the meter is employed afterwards in the other way, we not only get different interaction errors, but we are also liable to obtain errors due to the quadrature adjustment of the two meters not being exactly alike. One may be adjusted to read high on the leading current and the other high on the lagging current. On the whole, therefore, if we cannot reproduce actual working conditions and get the phases exactly as in working conditions, I think the single-phase test, if made with reversed connections, is probably about the best. I see that the authors do not recommend testing meters which have series transformers without their transformers, owing to the difficulty of measuring the ratio and phase-differences of the series transformers alone. This is not so very difficult. I can do it, and I dare say there are several others who can do it. But it is not sufficient to do that. There is in even a single-phase meter an interaction between the volt and ampere coils, which is of no consequence in the ordinary way when a meter is used without a transformer and running off a 100-volt circuit—that is to say, the pressure coils induce in the current coils a small voltage, which is of no consequence whatever compared with the pressure voltage of an ordinary circuit, but when used with a series transformer and when we get down to small loads this voltage is of quite material consequence. Recently I had a single polyphase meter with a series transformer to test which I found was creeping backwards on no load. As soon as I disconnected from the transformer it began to creep forwards--the direction of the creep was reversed. So it is evident that no measurement of the phase-difference and ratio error of the transformer alone would help us to obtain the right correction for this meter on small loads. That is the chief reason why, in my opinion, it is absolutely necessary to test all meters having series transformers with their transformers.

Mr. Edgcumbe. Mr. KENELM EDGCUMBE: Although not a manufacturer of house service meters myself, I feel that a paper of this sort is of very great interest and use to manufacturers. Curious though it may seem, my experience is that it is very difficult for the manufacturer to get into really close touch with the feelings of the users. Therefore I think that a paper of this sort in which the users "let themselves go" is extremely valuable. The authors have actually dealt with one class of user only, namely, the central station. Although it must be admitted that this probably covers nine-tenths of the total number of meters used, there is

Mr. Edgcumbe.

another class of consumer of some importance, and that is the isolated plant, and from my experience such consumers are rather difficult to deal with. Take, for instance, a country house installation. The load, for probably 360 days out of the year is very small, while, during the remaining five days, there are big functions going on, and the load goes up to a very high value. The contractor, knowing this when he puts in his plant, invariably orders a meter for a much larger current than he would do in the ordinary course, with the result that it is working throughout most of the year very low down on the calibration curve. For instance, in Fig. 1, if we assume the average load to be—as I think we might in such a case—about 20 per cent. of the rated maximum, there is an error of something like 6 per cent. going on throughout the year. I cannot help feeling that, in a case like this, the right thing to do would be to adjust the meter low down, and let the accuracy of the upper part of the curve look after itself. Heating has to be allowed for, but except for this it seems to me that, above half-load at any rate, accuracy is of very little importance. I am pleased to see that in the first paragraph the authors refer to the mistake of using the expression "wattmeter" for "watt-hour meter." There is another expression which they do not allude to, namely, "recording wattmeter." Our American friends are perhaps the greatest sinners in this latter respect, and it has lately become so troublesome, from our point of view, that my firm have decided to call the recorder proper a "graphic recorder," so as to have no doubt about it. On page 19 the authors give what, at first sight, appears to be a somewhat laborious way of adjusting for quadrature (that is to say, for making sure that, on an absolutely inductive load, the meter will stand still). They suggest adjusting the speed at unity power factor, and at 0·5, both leading and lagging. To make adjustments like that is a complicated business, and a much simpler method is to adjust for "standing still" with the volts 90° out of phase with the current. They raise against this latter test the objection that the wattmeter cannot be relied upon. Of course, there are "wattmeters" and wattmeters, but at the same time, I really cannot admit that a respectable wattmeter could be tried and found wanting by means of an induction watt-hour meter. I think a much more satisfactory way for polyphase work, and the one which I generally use myself, is to employ a power-factor indicator for the purpose. A polyphase power-factor indicator has the great advantage of being equally accurate at all phase angles, so that one can get extreme accuracy both at zero and at unity power factor, and it is further possible to use an unbalanced load instrument, in which case the actual conditions are exactly reproduced.

I should like to ask the authors how the wave-forms obtained artificially which they give compare with what they find in actual practice. At first sight it would appear that Nos. 2 or 2A were fairly vicious, but they seem to have very little effect on the meters, the greatest error being something under 2 per cent. I suppose it is necessary to conceal the identity of the various makers of meters as is done in the paper,

Mr. Edgcumbe.

but at the same time, if the authors could give us a hint, not as to the maker's name, of course, but as to the method of obtaining the quadrature in each case (that is to say, whether it is done by shunting the series coils or by a short-circuited winding on the volt magnet, and so forth), it would help very much in comparing the results with one another.

Mr. Baker.

Mr. C. ASHMORE BAKER: Although of course a large number of Electric Supply Companies have very excellent testing-rooms and very capable testing staffs, who do the whole work systematically, yet many other undertakings are not able to do their meter testing in such a systematic and thorough way, and they certainly suffer severely in consequence. Mr. Holden referred to checking tramway meters by contract and keeping them in order for so much per annum. Where central station managers are not well equipped with testing plant of the very best and most excellent description, they would be much better off at the end of the year if they had their supply meters maintained in that way. The authors suggest that meters usually remain in good condition for five years after testing. I think that that should be considered a limiting and not an average period, and should suggest an average of three years, although it is within my knowledge that meters which have come in after ten years' service have been found quite good, but that is of course an exception. On the other hand, where undertakers are dependent on the readings of their meters for big supplies—supplies of 50 H.P. and that sort of thing for industrial purposes—they would be wise to have their meters checked *in situ* very much more frequently, say at intervals of three or six months, to see that they are reasonably within the percentage error usually allowed. The reference to the ampere-hour metre shows the necessity for having "testing stations" on all the important systems of mains, so that the supply pressure has some sort of supervision as well as the current. There are some forty "testing stations" now on the London mains, and others are from time to time being equipped. These "testing stations" consist of one or more recording voltmeters, of a pattern approved by the Board of Trade as being suitable for the particular purposes, and such approval is usually granted in respect of any of the well-known types of recording voltmeters, provided that a portable indicating voltmeter is also provided for checking the recorder. The portable instruments require to be sent to the Board of Trade for test and certification as correct instruments. The recording voltmeters are sometimes connected to the pilot wires laid with the system of mains or in other cases connected to the mains on some consumer's premises, who may be willing to grant the necessary permission for a nominal consideration. The testing stations are established in compliance with the terms of the Provisional Orders and Special Acts granted to the supply undertakers, and an electrical inspector visits each testing station periodically, sealing up the instrument for several days' or a week's run, then attending again to remove the chart, which is brought to the office and returned the following day to the supply authority, with any comment, if necessary, as to the regulation of the

Mr. Baker.

supply pressure during the time of observation. I describe these testing stations somewhat fully, as I believe that they are the first stations of the kind equipped in compliance with the statutory requirements. The Continental practice of putting in watt-hour meters instead of ampere-hour meters has no doubt largely arisen from the fact that the manufacturers have taken a big financial interest in the supply undertakings, and have put in their own apparatus ; there has not consequently been so free a hand in choosing meters on the Continent as there has been in this country. On page 9 the authors severely criticise the electrolytic meter, and I should like to thoroughly endorse that; instead of stopping at the letter J, they should have gone on to X, Y, and Z, finishing up with &c., to complete, as far as possible, the points against such type of meter. It has one good point, however, it is very excellent in theory, but that is the only good point I know of ; it creeps owing to evaporation or to vibration ; the mercury sometimes is thrown over into the tube, owing to a door being slammed, and that sort of error is very difficult to discover during any ordinary test. When one examines the meter in the laboratory it appears to be quite correct, but the consumer is not happy about it, whilst the records of the meters are periodically destroyed, as are also the causes which have introduced errors into these records. After such meters have been re-set they certainly ought to be re-sealed, if they are meters which have been approved and certified in some form or other, because, in re-setting, the "shunt" is exposed and could easily be interfered with, or even another scale substituted for that used during the certification test. It is distinctly unfair to re-set this type of meter without notifying the consumer of intention to do so. It is, in fact, rather surprising that this type of meter has ever received the Board of Trade approval ; it takes weeks to test, and even then cannot be accurately read to within the $2\frac{1}{2}$ per cent. margin allowed on either side of the correct register. As to shunts, I think it will be generally accepted that shunts are frequently desirable—I mean, of course, the heavy current-carrying shunt. The shunt does not get out of order ; it usually keeps in quite good order, and it keeps a lot of heat outside the case rather than dissipating it inside. The mechanical movements of meters are apt to get out of order, to get dirty and slow, but the shunt usually remains constant, and is no cause of worry after it has been carefully adjusted. As to testing meters, it is suggested that 1 per cent. error is highly desirable. Now, most meters come well within 1 per cent. on top loads ; it is at low loads that the limits of error have to be considerably widened. When the matter was before the Standards Committee a formula was introduced by one of the members and adopted by the Committee ; this dealt with errors of all loads from $\frac{1}{10}$ down to $\frac{1}{20}$ load in a very pleasing manner, by dividing the denominator of the fraction expressing the load by 4, *i.e.*, at $\frac{1}{16}$ load the permissible error would be 4 per cent., but this formula does not appear to have come into everyday use. I am sorry that the Board of Trade are dropping the accuracy tests altogether below $\frac{1}{10}$ load for everything except the

Mr. Baker. 50-ampere or larger meters. It is not perhaps realised that an error of 1 per cent. on a clock represents an error of about 40 minutes per week. Such an error would render a clock useless, whilst what may be considered a permissible error, say 2 minutes per week, represents an error of only 0·02 per cent.; the comparative figures are interesting, but the varying load to which the electricity meters are subject makes it impossible to attain the accuracy of the clock with its constant load. Mr. Edgcumbe referred to the case of a country house which had a big meter put in to deal with its occasional maximum load. The case of a big town house is frequently very similar, because the town-house people have big functions occasionally and require a big meter to measure the supply used at those functions, whilst during the nine or ten months of the year that the proprietors are out of town their caretakers are using only a few lamps, and are consequently very much on the low part of curve No. 1.

As to errors which have been discovered in meters brought in for re-testing, the authors no doubt have had some very interesting experience, but they do not tell us about it. Quite recently an error came to light in the London County Council meter testing station of a nature due to the cyclometer gear being out of step. Instead of the meter reading up to 99 and then 100, it went from 68 to 169; it gradually climbed up to 178, 188, 198, and then the reading became 108, and so on until it got up to 168, when it at once jumped to 269, and followed on this erratic course. The connection between the 100 and the 1,000 gear-wheels was likewise out of step, and the readings on which the accounts were based were altogether unreliable. The cause was due to the gear-wheels being only friction-tight on the spindles; they should always be rigidly attached, so that when once accurately set it is not possible to alter them relatively to one another. In another instance, it happened that a consumer had a meter which was calibrated for reading units on a circuit of 200 volts, and it was working on a 100-volt circuit, so that he was being charged for double the energy that he was using. There are many instances of that sort which are of great practical interest, but time prevents my going through them. Meter testing must be done with absolutely reliable instruments, including stop-watches; it would be very unsatisfactory for anybody to do meter testing with instruments which tell falsehoods. Some of the instruments in use should be checked daily against the sub-standards, and every instrument should be so checked at least once a week. As to the universal testing of meters by an independent authority and the sealing of such meters as are found to be correct, this is a question that is still very open and undecided. There is little doubt that this was intended when the Electric Lighting Acts were originally drafted, but no serious case has been contested, and so there is uncertainty, and a loophole for the use of uncertified meters. Gas meters are so tested, and so are all weights and measures generally. It would be much more satisfactory for every consumer to know that his meter had been tested by an independent authority, but I doubt if he would generally have a

smaller bill to pay. Recently in discussing the matter with an eminent K.C., who as a consumer happened to dispute the reading of his meter, he told me that he was quite unaware that the law was such that an electric meter might or might not be certified, and when an eminent K.C. is weak on those points, the ordinary consumer obviously lacks information. Mr. Baker.

In regard to the interesting experiments showing the effect of varying wave-forms on the accuracy of meters, it is satisfactory to note, from the consumer's point of view, that when a meter has been tested with an alternating current approximating to the sine curve, the meter tends in almost every case to run more slowly if put in circuit with an alternating-current supply of any other wave-form.

Mr. A. P. TROTTER: It is almost useless for me to say that I rise in a purely private capacity, as I generally try to do. At the same time, there are a good many things I would like to say about this paper which I do not want to say; I would much sooner they came from meter makers. Some things have fallen from meter makers which I am very glad to hear, because it does not necessitate my dealing with them, and other things might have been added if meter makers and meter users had chosen to combat the pessimism of this paper. Mr. Trotter.

The authors of this paper have not described the different classes of meters as clearly as they might have done. They were unwilling, doubtless, to give names. The "commutator type" of ampere-hour continuous-current meter is simply a motor meter; it has an armature and a commutator and a field, and goes round as an ordinary motor. Then, with regard to the continuous-current dynamometer, we know what dynamometers are, but we hardly recognise the type of meter which is fairly well described as an ironless motor. Then again, the alternate-current dynamometer is nothing more than an alternate-current motor; and finally the induction meter is a rotating field, or Ferraris motor. With those classifications the paper would have been more clear; one would have visualised better what meters were being discussed. I stumble on the words "legally recognised" as early as the second page; the authors do not want ampere-hour meters to be legally recognised. Well, I am sorry for it; but the Provisional Orders have said that energy may be measured by what the lawyers call, and nobody else calls, "the quantity contained in the supply"—that means ampere-hours. Coming to the ampere-hour meters, I cannot agree about those losses. The losses in small watt-hour meters are very large, if the loss is taken as a percentage of what is registered by them; so much so that it would be hopeless to make a small watt-hour meter. There might be 50 per cent. loss on what goes through. I am speaking of a very small watt-hour meter well below 3 amperes, because now is the time to encourage the small meters. If the small meters are not to be made, undertakings are going to do without meters. It is the day for small meters, and they should be encouraged. It is rather curious to hear that all mercury meters "are more or less based on the original Hookham models." We know the admirable series of Hookham

Mr. Trotter. meters, but just imagine our President's name left out when the authors talk about mercury meters! This unwillingness to give names has been carried rather too far.

Fig. 1 gives a curve purporting to represent the performance of "commutator-type" meters. I have seen some bad meters and have heard of others, but I do not think I have ever come across a curve of this kind, unless for a meter obviously out of order. I am very sorry that this curve should be published as indicating common practice in meter work. Consumers, indeed, would have no cause for complaint, but what supply engineer would throw away his employer's revenue by using such a meter? I am rather sorry Mr. Baker did not give us some analysis of his hundreds or thousands of tests. He could have told us what proportion of meters is as bad as this; a very small one, I think. Of course it goes without saying that it would nothing like pass the Board of Trade tests, nor would a meter which was likely to get into that state after two or three years. However, it is a thing for the makers to defend if they feel that is a just criticism.

On the next page electrolytic meters are dealt with. We have been blamed for passing them, but we do not want to discourage too many meters. Perhaps we are wrong in having approved 49 different kinds of patterns of meters; and there are 20 in hand now under test, and more are still coming on. Among that number, of course, there have been some meters which have been withdrawn—which have died a natural death. But the electrolytic mercury meter is not as bad as is made out. The second of the objections set out on page 9 is "impossibility of reasonable repair." I should think some of the makers would be rather thankful if their instruments were as well guarded against meddling as is the internal construction of a mercury meter; because the way people take meters apart and pull them about must be rather appalling—at least so they tell me. With regard to the high voltage drop, the customary practice has been a maximum of 2 volts, and I think that some small ampere-hour motor meters might well spend a larger drop than they do if a cheap small meter is to be encouraged. I think they can well spend 2 or 3 volts when it is remembered that the 200-volt supply is a common one. As regards the spilling of mercury, if a meter is going to spill its mercury by the slamming of a door it ought not to be fixed in such a position. On page 10 the authors state their opinion that "All meters should be so constructed that they may be both read and sealed." Since 1890 one of the requirements for approval has been that they could be all sealed. Provided the workmanship is good the smaller a commutator is the better. Obviously the friction is less, and many of them have only three sections. The effect of overloads and short circuits on magnetic fields is a very serious matter. Makers are now well aware of this. I think meters for use in tramway generating stations are fairly well able to stand the short circuits.

The last part of the paper, dealing with polyphase working, is of importance; and I agree with the authors that there is a difficulty in getting an accurate polyphase meter, and that it is necessary to allow a rather

larger error in polyphase meters than in single-phase meters, because of the great difficulty of balancing the two. The two have to be adjusted. It is not like making two correct meters; we have to make a double meter, and there are constructional difficulties which I think might have been brought out by the authors. The wave-forms are very interesting, but Table II. is a little too alarming. A large power consumer picking up this paper and looking at the table and seeing this enormous error of 27 per cent. would say, "What is the good of electric meters if they are going to do this?" I think the authors should have admitted that in the last part of the test they used fancy curves that are not likely to be found in practice. I do not think that either the high ideal of the authors or their low opinion of electricity meters is likely to help the industry. They speak on page 27 of a meter to "be produced at a reasonable price and having an error not exceeding 1 per cent.," and they think that legal permissible limits of error are retrograde if this standard is not maintained. Makers could produce such a meter, but it cannot be done at a reasonable price. Very good meters can be got extremely cheaply at the present time. The "pattern and construction" of no meter is approved by the Board of Trade unless the errors of the specimens submitted are less than 2 per cent., plus or minus, above $\frac{1}{10}$ load. It is assumed that good specimens are picked for approval and another $\frac{1}{2}$ per cent. is allowed by inspectors for ordinary meters. Some years ago we found there was a very obvious demand for small meters of less than 3 amperes, and we thought that those should be encouraged. I do not quite like to see new systems which do without meters altogether. It may be that some very excellent systems do without meters; but, still, one likes to see a cheap small meter for the small householder. That being so, we relax 1 per cent., and suggest that for meters of 3 amperes and under the error should not be more than 3 per cent., plus or minus, for the "approval" test, and $3\frac{1}{2}$ per cent., plus or minus, for ordinary meters in use. That has been going on for the last ten years. At the suggestion of the County Council, a special provision was made for meters above 50 amperes. At $\frac{1}{20}$ full load the error must not exceed $2\frac{1}{2}$ per cent. plus; that is to say, it can go as slow as it likes, but it must not go $2\frac{1}{2}$ per cent. fast. Mr. Trotter.

Mr. S. EVERSHED: The authors refer to the demagnetising of brake magnets in meters by excessive current in the current coils. A few years ago it was a popular notion amongst meter makers that a short-circuit current might be reckoned as about twice the full-load current. The simplest experiment is sufficient to show how large a short-circuit current may be on a lighting circuit. Several years ago I made some tests on a 100-volt 10-ampere lighting circuit, protected by ordinary fuses which melted at 20 amperes. On making a short circuit, the current rose to 340 amperes before the circuit was severed by the melting of the fuses. The full-load drop on the circuit was 3 volts, and hence the resistance was $\frac{3}{10}$, and on short circuit the current would rise to $100/0{\cdot}3 = 330$ amperes. It is important to know whether Mr. Evershed.

Mr. Evershed.

in all ordinary cases the current has time to reach its steady value, and Professor Schwartz in Manchester undertook some oscillograph experiments for the Standards Committee which showed very clearly that when the fuses are blown the current has ample time to reach its steady value before the circuit is broken, at all events on any ordinary lighting circuit. That being so it is quite easy to calculate what the short-circuit current on a lighting circuit might be. It is only necessary to put the full-load current of the meter through the circuit and note the drop up to the short-circuit point. The ratio of the drop to the working voltage of the circuit is the factor by which the full-load current must be multiplied to give the approximate strength of the short-circuit current. Supposing the drop up to the point where the short circuit takes place is 3 per cent., and the volts, we will say, are 100, then the short-circuit current will be about thirty times the full-load

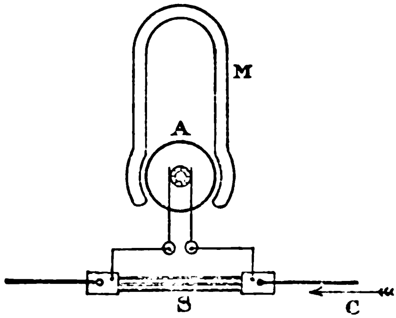


FIG. D.—Shunt Motor Meter.

current. If the volts are 200 it will be sixty times, and so on. I hope meter makers—and still more, meter buyers—will realise what that means. Let the buyer subject each type of meter to a practical short-circuit test, and in that way weed out many of the cheap meters now on the market. A great deal has been said about what the authors call the "commutator motor meter." It is a very good example of the cheap meter both in its merits and its defects. This type is based on the shunt motor meter, invented by Mr. J. Swinburne in 1891. It was re-invented some four or five years later by Mr. O'Keenan, and was then made by the French Meter Company, who sold it as the "O.K." meter. But to-day many makers, besides the French Company, are making shunt motor meters of the same type. The principle is shown in Fig. D. S is a resistance or "shunt" in the supply circuit carrying the main current C. The armature A of a small electric motor is connected in parallel with S. The field is provided by a permanent magnet M. As Mr. Swinburne showed, if the armature had no resistance, and the friction of the brushes and the bearings was nought, the meter would be accurate. It never is accurate because neither

Mr. Evershed.

the friction nor the resistance can be reduced to zero. The law of the meter is as follows: If C is the main current, R the armature resistance, r the "shunt" resistance, B the flux through the armature, N the turns of wire on the armature (per parallel), and f the moment of friction, then speed of armature $= C\,r/4\,B\,N - 2\,\pi f\,(R + r)/(4\,B\,N)^2$ revolutions per second; all the quantities being measured in C.G.S. units, of course. The formula is for a meter with no brake; the addition of a brake lowers the speed and increases the armature current, but does not affect the product $2\,\pi f\,(R + r)$. The second term in these equations is always the interesting one; evidently the accuracy of the meter depends on the product of friction and resistance. It would be thought that the first thing a maker would do would be to attempt to get the friction moment and the resistance more or less equal, so as to reduce the product to a minimum. Not one of the makers attempts to do that—indeed, one maker even prides himself on the high resistance of his armature. The next thing to notice is that if the flux were doubled the speed of the motor would be halved, which would be a very good thing, because these meters mostly run at high speeds; 300 or 400 revs. per minute is by no means uncommon. Moreover, with twice the flux the error term will be only one-fourth the original value, and the meter would not only run slower, but would be very much more accurate. Is that what the makers of those meters do? No, they and their customers are all infatuated with the mania for cheapness. To increase the flux means a larger magnet and a bigger meter, and a consequent increase in the cost. Rather than pay more money the buyer will cheerfully sacrifice revenue by the use of meters which run slow. I can fully confirm the figures given by Mr. Melsom for the errors of this type at $\frac{1}{10}$ load. I have tested most of the direct-current meters on the market, and in the annexed table I give the errors found in three shunt motor meters supplied by three different makers.

SHUNT MOTOR METERS.

Table showing the Percentage Error (Slow) at different Loads.

Load.	$\frac{1}{10}$	$\frac{1}{4}$	$\frac{1}{2}$	Full.
Meter A ...	14·5	3·0	0·7	0
Meter B ...	10·0	3·2	2·0	0
Meter C ...	87·0	35·0	15·0	0

I bought these meters direct from the makers, and in each case they were delivered with the cases sealed, the accuracy being guaranteed by the maker provided the seals were not broken. They were therefore tested with the seals intact.

Mr. Evershed. It must not be supposed that the inaccuracy is wholly due to bad workmanship. On the contrary, meter B was well made, and meters A and C fairly so. Inaccuracy is inherent in the principle, and large errors are mainly due to bad proportion between resistance and friction, and variable contact resistance at the commutator brushes. Better results might be obtained if the buyer could be induced to think a little less about cheapness and a little more about the loss of revenue from slow meters.

Mr. Rayner. Mr. E. H. RAYNER (*communicated*): The paper will be most useful to engineers who are in charge of supply undertakings, as it will give them definite information on many points as to the use and testing of integrating meters which it is impossible to obtain without lengthy experiment, involving the use of expensive plant and instruments. The choice of proper testing apparatus is a matter of the greatest importance, and involves a knowledge of the various types of meter on the market and details of their internal design, especially in the case of instruments used for alternating current. In the case of instruments for use with direct current the ultimate standard is naturally the potentiometer. Unsuspected serious errors may arise even with so simple an instrument as the potentiometer, especially when connected up to two circuits, such as is commonly the practice in testing wattmeters and watt-hour meters. For testing such instruments two sources of supply should be used, as mentioned in the paper. The pressure coil is supplied from a large number of small cells at high voltage and the current coil by a few cells of large capacity. These are often used in parallel and charged in series. It is convenient to use sets giving 4 or 6 volts, rather than single cells, as then a large fraction of the pressure may be used in resistances of very small temperature coefficient with corresponding steadiness of current. In checking the current and voltage by the potentiometer, one troublesome source of error is leakage from one circuit into the other; and on account of the high resistance necessarily used as a potential divider for the volts this error may seriously affect the accuracy of the observations. Ebonite is usually regarded as a perfect insulator; but it is liable to surface decomposition, especially when subjected to light. The effect is hastened by a damp, warm atmosphere, and it is sometimes appreciable in a few hours. Practically all commercial ebonite is affected in this way. The consequence is that instead of an infinite resistance over the surface of a piece of ebonite it is well to assume a comparatively low insulation resistance. The leakage current may become quite appreciable in comparison with such small currents as are commonly used in potential dividers. It is a simple matter to arrange the connections so that this effect is negligible in ordinary circumstances. A selector switch is generally used in connection with the potentiometer. Before the circuits reach this switch they should be independently caused to take approximately the same potential, preferably earth potential. This may be done by connecting the sources of supply to earth, which may be conveniently

done through lamps (L_1 L_2 in Fig. E). By this means the various connections to the measuring apparatus cannot differ from one another by more than one or two volts. A simple change-over of the connection to the earthing lamp of the volt battery from A to B will at once indicate, by the alteration of the balance of the potentiometer, whether there is likely to be serious error if this arrangement is not used. It is necessary to insulate thoroughly the potentiometer battery, its adjusting resistance and the standard cell. Blocks of paraffin may conveniently be used, which should occasionally be washed. Mr. Rayner.

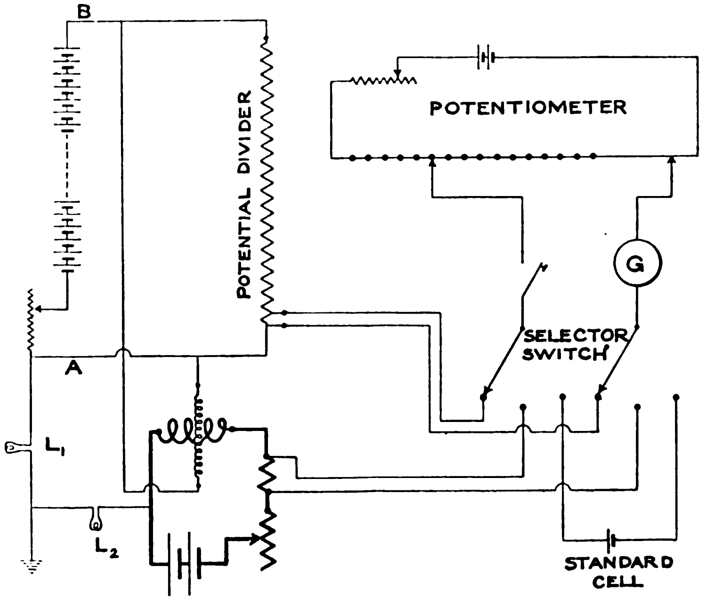


FIG. E.

There is another trouble which may occur if the circuits are not approximately at earth potential. This is caused by the galvanometer G acting in part as an electrostatic instrument. If a circuit is switched on to it, which is at a considerable potential from earth, it may produce a deflection, and if there is in addition some leakage to the case, a current may also pass through it to earth. The best way is to connect the case to one terminal of the instrument and thoroughly to insulate the whole. This electrostatic effect may occur with ordinary portable moving-coil instruments, and may produce serious errors which are not easy to detect unless definitely looked for. The same method of connecting one terminal to the case is the remedy. For testing alternating-current meters the authors describe the necessary apparatus, to which might be added, for accurate work, a battery of

Mr. Rayner. several kilowatts' capacity for driving the motor-generator, unless the supply obtainable is exceedingly steady. The control of the rotating stator of one of the alternators by an electric motor from the testing bench is a great convenience in adjusting the power factor. An alternating standard voltmeter may be of the dynamometer moving-coil type, and in order to minimise the error due to self-induction and consequent variation with frequency, iron is inadmissible. Very satisfactory instruments giving 1 in. of scale for 10 per cent. variation in volts at the usual supply voltages are now obtainable. This sensitivity is amply sufficient for commercial work. A more perfect but more delicate instrument needing further apparatus for its proper calibration is the reflecting electrostatic voltmeter. The standard instrument at the National Physical Laboratory has an openness of scale 30 times the above value. For commercial work a precision dynamometer-instrument is more satisfactory, and when once the self-induction error has been determined its calibration on continuous current is a simple matter. The measurement of current is, commercially speaking, a matter of minor importance in alternating supplies—a point emphasised by the practical non-existence of ampere-hour meters, as stated by the authors. Moving-iron instruments may be generally used.

On the very important question of wattmeters much might be written. The main source of error other than the error caused by the self-induction of the shunt coil, which should be almost inappreciable when a high resistance is used in series with it, is caused by eddy currents. These may be produced either in the metal of the active parts of the instrument, or in other metallic parts influenced by the magnetic fields of the coils. For this reason unnecessary metal is entirely avoided in the best types of laboratory standards, and the conductors are thoroughly stranded. In some otherwise excellent instruments, brass formers, etc., are used to make a more rigid construction in portable instruments. The error is then liable to be distinctly appreciable even at 0·5 power factor in spite of cutting the metal through to intercept the main path of the eddy currents. It could probably be made negligible if some high-resistance alloy were used instead of brass. This serious defect, in what are otherwise very perfect instruments, should receive special attention from the manufacturers of the dynamometer wattmeter, which is the most important instrument in alternating-current engineering. For the highest precision and research work, and for the determination of errors in instruments of the above type, an electrostatic instrument is essential. The special incidental apparatus required makes it impracticable for ordinary test work except in laboratories with unusual facilities and equipment. At the National Physical Laboratory it is in daily use for the determination of the errors in wattmeters and watt-hour meters. As with voltmeters, when once the intrinsic errors due to shunt inductance, eddy currents, etc., have been determined, the dynamometer wattmeter may afterwards be calibrated by direct current.

The portion of the paper dealing with alternating-current watt-hour meters of the induction type is perhaps the most important, as it ventilates a subject which requires very complete apparatus for satisfactory investigation, and is therefore beyond most testing establishments. The perfection which has been reached in the induction meter is due to the use of dangerous voltages. For satisfactory measurement on such systems it is necessary to use pressure and current transformers, and to earth one pole of the secondary of each. The current transformers can be made for any convenient current on the secondary side, and it is to this fact (5 amperes having become the full-load standard) that the development of the induction meter is due. A large current would be quite impracticable in the ordinary type of meter. As meters of this class for any but small loads and low voltages are all of identical size, being wound for 100 or 110 volts and 5 amperes, a very large expense in design has been justified, and the automatic correction of errors has been carried to a high degree of perfection. At the same time, when these adjustments are not correctly made, the errors in the instruments may be very considerable, just as in any other meters; and as the calibration is a very different matter from that of continuous-current instruments, they are much more liable to be found in incorrect adjustment. This is especially the case with polyphase instruments. Meters of this type are often sent to standardising institutions after having been used on important tests of plant, the results of which may involve large sums of money, and occasionally rejection, if the machines do not comply with specified efficiencies. These tests are often made, using only one induction meter, which is generally sent to be standardised only after the test, and no note is made as to which element of the meter it is which leads when used on a 3-phase circuit. Instruments have been sent in in this way which have been found to be completely out of adjustment by the breakage of internal connections, after being used on a very expensive series of tests, which have been quite useless. Mr. Rayner.

Although, as has been mentioned above, a properly adjusted induction meter is a very satisfactory instrument, yet perfect adjustment is not possible without the use of first-rate standard instruments. When required for use on important tests, they should always be standardised before being used, and again afterwards, when a comparatively short test will show whether the instrument has altered. In general, for ease and accuracy of adjustment and calibration, two separate single-phase instruments are much more satisfactory than the usual double type for polyphase work, as indeed the interaction of the meters as described in the paper amply proves. For really satisfactory tests an integrating meter of this type should always be supplemented by indicating instruments of the dynamometer type. These should be calibrated *en bloc* with their pressure and current transformers. The latter are now obtainable with various secondary tappings to enable accurate readings to be made at various loads. In connecting watt-hour meters to 3-phase circuits, care should be

Mr. Rayner. taken that they are connected up, just as they are on the test-bench. The makers should mark their meters accordingly, not only as regards the leading and lagging elements of the meter, but also which of the volt terminals are to be "common" when used to measure a 3-phase circuit by the two-wattmeter method.

The question of the determination of the power factor of a circuit has been mentioned in the discussion. This is defined as the ratio of the true watts to the volt-amperes. In practice this will never reach unity, unless volt and current waves are identical in shape—which is almost impossible on ordinary circuits. In practice, a more convenient method of defining the power factor is to take the ratio of the watts to the "maximum watts in the circuit when the volt and current vectors are rotated relatively to one another till this condition is reached." As in practice a wattmeter should always be used, the accurate determination of the power factor is of minor importance, and the error in the above assumption is quite unimportant except at small phase-differences accompanied by large differences between volt and current wave-forms. In meter testing the power factor can be very easily determined by taking the ratio of the reading of the standard wattmeter to the reading obtained when the movable stator is rotated till the reading is a maximum.

Mr. Fawssett. Mr. E. FAWSSETT (*communicated*): In the case of large consumers, I would suggest that the proper course is to test the meter frequently in position rather than to remove it at all, except at long intervals for more thorough overhaul. The frequency of the test will depend on the importance of the supply, the position, and type of meter, and would finally be based on the periodic inaccuracies found. I do not agree with the very favourable case the authors make out for a watt-hour meter on ordinary small consumers' supply. Good up-to-date ampere-hour meters can be reasonably accurate at 1 per cent. of their rated load and retain their accuracy, but the ordinary type of watt-hour meter either creeps or does not go on such a load according to the amount of vibration present. Having taken a large number of voltage records in consumers' houses, I do not agree that the average distributor pressure is 2 per cent. above the declared value in a good 3-wire system, especially at times of heavy load, though the feeding-point is approximately that amount. Experience has, however, shown that interest on first cost, depreciation, and maintenance much more than balance any small theoretical gain, itself largely hypothetical according to the average accuracy figures obtained from the two types before installation and after removal. Total disintegration of mercury is very rare; there has been no such case among 6,000 meters in the last six years. Heat is the chief cause of mercury trouble, and it is important to keep down the bath temperature, especially if ebonite is present. An all-metal bath is much to be preferred. The curve given on page 8 exactly confirms my experience of the two types, except that commutator meters "off circuit" give very much worse results, the mean of a batch of

Mr. Fawssett.

24 giving a test 30 per cent. slow on $\frac{1}{10}$ load, though all the meters continued to rotate on 1 per cent. of rated load. I certainly think the authors are too sweeping in their condemnation of mercury watt-hour meters. There is no more trouble with the mercury, provided: (1) the bath current is kept down below a point at which heating can set in; (2) the losses in the pressure circuit do not heat up the bath; (3) the bath is of metal, not ebonite. These conditions have been met by one well-known firm, but extensive experience of earlier types not complying with the above conditions compels me to take exception to the assertion. A large number of these meters have been periodically tested for accuracy, and also bath resistance, and in the two or three cases where changes have taken place the percentage error has not been very large, and was always traceable to undue heating.

Seeing that single-phase induction meters by at least one firm have a torque of 10 gramme-centimetres at full load, I think the author's complaint of low torque scarcely justified. The section on polyphase meters is to me the most interesting part of the paper, on which the authors have evidently spent a great deal of time, but here again I think they are rather too much inclined to the view that nothing on the market is any good. Their remarks on the great effect of both direct and alternating stray fields are quite justified. I should certainly place the meters for a direct-current generating station in a house to themselves away from switchboard or plant. The five methods of phase adjustment given on page 32 are interesting, and I am glad to note that the authors prefer (*b*). This has been in use in the testing department of the North-East Coast Companies for some time in conjunction with (*e*). The phase-angle of the current transformers being easily tested at the same time as the in-phase ratio, by using wattmeters instead of ammeters, polyphase meters may be tested without their current transformers, the small difference to compensate for the lead of the current transformers being allowed on the power-factor adjustment between "lag" and "lead." The method (*e*) is perfectly satisfactory if properly used, and balanced load kept on all three phases—three stepped lamp-boards allow for this; and by using a specially constructed switch the meter may be tested at all the necessary points, by merely changing the phases exciting the current coils.

The curve shown in Fig. 20 would have been still more interesting if carried through to leading power factor vertically, as the power-factor of W_1 and W_2 are not the same at "unity 3-phase," one being leading and the other lagging. The tests for interaction on page 47 *et seq.* would have been much more interesting if the meter had been connected as a polyphase meter with the two pressure coils excited 60° apart (for 3-wire, or 120° for 4-wire). I have made various tests in this direction, and with the meter properly connected the only serious error with all possible changes is that when the volt coil on one element is opened, this causes an average over-registration on

Mr. Fawssett. the live phase of 4 per cent., but such a condition is impossible in practice. Opening the current circuit has an average effect of 1 per cent. Taking a meter properly adjusted for balance, power factor, and load curve, a series of tests were made to find out what was the effect of changing over the elements into different phases, and reversing both current and pressure in each element separately and together. Tests were made on 100 per cent. and 50 per cent. load "3-phase unity," and on 50 per cent. load "0·5 lag 3-phase," and "0·5 lead 3-phase."

Thus with a particular phase chosen for the one element the worst deviation from the mean is 0·4 per cent. with any connection possible, and if the phase is not specified there is a possible further average

TABLE

Top element	V 3-2 C 3-N	V 3-2 C 3-N	V 2-3 C N-3	V 2-3 C N-3	V 1-2 C 1-N	V 1-2 C 1-N	V 2-1 C N-1	V 2-1 C N-1
Bottom element	V 1-2 C 1-N	V 2-1 C N-1	V 2-1 C N-1	V 1-2 C 1-N	V 3-2 C 3-N	V 2-3 C N-3	V 2-3 C N-3	V 3-2 C 3-N
Mean registration on the 4 loads	100·6	100·3	100·9	100·9	101·4	101·3	101·6	101·3
	100·7				101·4			

N.B.—All the phase above volt and current vectors are at 30° for "unity 3-phase."

error of 0·7 per cent. But it is perfectly simple to mark the element terminals for connection to a particular phase, and to test with the same cyclic rotation; this is our standard practice. Such a polyphase meter is a remarkably accurate instrument on reasonable wave-forms, but it should always be calibrated with 3-phase current as above outlined, and not with single-phase.

Mr. Young. Mr. ARTHUR P. YOUNG (*communicated*): On page 6, under the heading "Troubles Due to the Use of Mercury," we read that "shunting has the additional advantage of reducing the somewhat considerable temperature error; but errors on fluctuating loads may be introduced unless the inductances of the shunt and bath circuits are balanced." Now the latter part of this paragraph deals with a point of considerable practical importance, but the statement, as I propose to show, is quite erroneous.

Fig. F gives a diagrammatic representation of the two circuits, connected in parallel, which have to be considered. Suppose— Mr. Young.

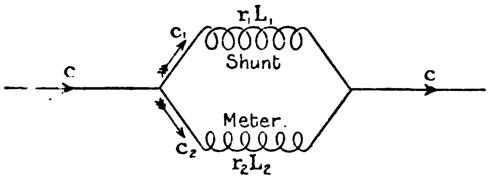


FIG. F.

Resistance of shunt circuit	$= r_1$.
Self-induction of shunt circuit	$= L_1$.
Instantaneous current through shunt circuit ...	$= c_1$.
Resistance of bath circuit	$= r_2$.
Self-induction of bath circuit	$= L_2$.
Instantaneous current through bath circuit ...	$= c_2$.
Instantaneous line current	$= c$.
Instantaneous angular velocity of moving element...	$= \omega$.
Moment of inertia of moving element	$= I$.

Then it follows from Kirchhoff's laws that at any instant—

$$c_1 r_1 + L_1 . d c_1/dt = c_2 r_2 + L_2 . d c_2/dt \quad . \ . \ . \ . \quad (1)$$

and—

$$c = c_1 + c_2 \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad (2)$$

We are assuming that the line current c is fluctuating, then if we neglect the friction in the meter, the equation representing the motion of the moving element is—

$$k . c_2 = I . d\,\omega/dt + k_1 \omega \quad . \ . \ . \ . \ . \ . \ . \ . \quad (3)$$

where k and k_1 are constants.

From equation (1) we get—

$$c_2 = r_1/r_2 . c_1 + L_1/r_2 . d c_1/dt - L_2/r_2 . d c_2/dt.$$

Substituting this value of c_2 in equation (3) we get—

$$(k\, r_1/r_2)\, c_1 + (k\, L_1/r_2) . d c_1/dt - (k\, L_2/r_2) . d c_2/dt = I . d\,\omega/dt + k_1 \omega.$$

Now if we consider the period between an initial time T_1 and a final time T_2, we get by integrating the above equation, after multiplying through by dt—

$$\left(\frac{k\, r_1}{r_2}\right) \int_{T_1}^{T_2} c_1 . dt + \left(\frac{k\, L_1}{r_2}\right) \int_{T_1}^{T_2} d\, c_1 - \left(\frac{k\, L_2}{r_2}\right) \int_{T_1}^{T_2} d\, c_2$$

$$= I \int_{T_1}^{T_2} d\,\omega + k_1 \int_{T_1}^{T_2} \omega . dt \quad . \ . \ . \ . \ . \ . \ . \ . \quad (4)$$

Mr. Young. If we assume that initially and finally the moving element is at rest, then at each of the times T_1 and T_2 considered, c_1, c_2 and ω must each be zero. It is therefore apparent that—

$$\int_{T_1}^{T_2} d\,c_1 = (c_1)_{T_2} - (c_1)_{T_1} = 0$$

$$\int_{T_1}^{T_2} d\,c_2 = (c_2)_{T_2} - (c_2)_{T_1} = 0$$

and—

$$\int_{T_1}^{T_2} d\,\omega = (\omega)_{T_2} - (\omega)_{T_1} = 0.$$

That is, equation (4) can be reduced to—

$$\left(\frac{k\,r_1}{r_2}\right)\int_{T_1}^{T_2} c_1\,dt = k_1\int_{T_1}^{T_2} \omega\,.\,dt \quad \ldots\ldots \quad (5)$$

From equation (2) we get, after multiplying through by dt and integrating—

$$\int_{T_1}^{T_2} c\,.\,dt = \int_{T_1}^{T_2} c_1\,dt + \int_{T_1}^{T_2} c_2\,dt \quad \ldots\ldots \quad (6)$$

By treating equation (1) in the same way we get—

$$r_2\int_{T_1}^{T_2} c_2\,dt = r_1\int_{T_1}^{T_2} c_1\,dt + L_1\int_{T_1}^{T_2} d\,c_1 - L_2\int_{T_1}^{T_2} d\,c_2.$$

That is—

$$\int_{T_1}^{T_2} c_2\,dt = \frac{r_1}{r_2}\int_{T_1}^{T_2} c_1\,.\,dt.$$

Substituting this value of $\int_{T_1}^{T_2} c_2\,dt$ in equation (6), we have—

$$\int_{T_1}^{T_2} c_1\,dt = \frac{r_2}{r_1 + r_2}\int_{T_1}^{T_2} c\,.\,dt.$$

Finally, substituting in equation (5), we get—

$$k\left(\frac{r_1}{r_1 + r_2}\right)\int_{T_1}^{T_2} c\,.\,dt = k_1\int_{T_1}^{T_2} \omega\,.\,dt \quad \ldots\ldots \quad (7)$$

The integration $\int_{T_1}^{T_2} c\,.\,dt$ simply represents the total ampere-hours used in the period of time between T_1 and T_2, and the integration

$\int_{T_1}^{T_2} \omega . dt$, the total number of revolutions made by the moving element in the same period. Mr. Young.

If we imagine that both shunt and mercury bath are perfectly non-inductive, and, further, that the load is perfectly steady, then the equation of motion of the moving element becomes simply—

$$k c_2 = k_1 \omega \quad \ldots \ldots \ldots \quad (8)$$

and also—

$$c_2 = \frac{r_1}{r_1 + r_2} . c.$$

Therefore by substitution in equation (8)—

$$k \left(\frac{r_1}{r_1 + r_2}\right) c = k_1 \omega \quad \ldots \ldots \ldots \quad (9)$$

The velocity ω will now, of course, be absolutely constant, so that if we consider a period of time T we get—

$$k . \left(\frac{r_1}{r_1 + r_2}\right) (c T) = k_1 . (\omega T) \quad \ldots \ldots \quad (10)$$

Writing this in another way—

$$k \left(\frac{r_1}{r_1 + r_2}\right) \times \text{ampere-hours} = k_1 \times \text{total number of revolutions} \quad (11)$$

Comparing this with equation (7), deduced above, it is at once seen that the constants on both sides of the equations agree exactly, and we can therefore conclude that the constant of the meter is not affected by inductance in either shunt or bath circuit, and simply depends on the resistances of the two branches, no matter how the load fluctuates.

The question of the accuracy of a meter on rapidly fluctuating loads is often raised, and it can be shown that all motor meters in which eddy-current braking is employed possess the common—and essentially important—property, that they are unaffected by such variations. In deducing this result the assumption is made, as has been done in the foregoing analysis, that the friction tending to retard the motion of the moving element is zero. If we consider loads between full and one-tenth of full load, the characteristic curve of any well-designed meter is practically straight over this range, neglecting any compensating device, so that in such cases our assumption with regard to the friction being negligible is for all practical purposes correct.

Mr. E. B. SCHATTNER (*communicated*): As some of the opinions expressed in the paper would, if unanswered, be likely to affect unfavourably the natural development of ampere-hour meters of the commutator type—a type of instrument in which I thoroughly believe —I will endeavour to point out a few facts which have been overlooked by those who so freely expressed an adverse opinion on this type Mr. Schattner.

Mr. Schaltner.

of meter. It was stated that those commutator meters which had come under notice had developed serious inaccuracy, particularly at low loads after a period of service; that a characteristic trouble was that of insulation breaking down under the commutator segments; and that, in short, reliability should not be expected from this type. It will be useful, therefore, if I briefly state the commercial history of the commutator meter. As pointed out by the authors, the meter is of Continental origin, and was introduced to supply the demand for a simple ampere-hour meter not so liable to derangement as most of the existing watt-hour meters. The mercury meter was at that time not known on the Continent, and was also very imperfect as manufactured in England. The commutator ampere-hour meter was therefore designed by the leading Continental firms to be suitable for Continental climatic conditions, and to comply with the conditions of electrical standardisation and supply which obtained on the Continent.

Briefly, the following conditions had to be taken into account: 1. Generally speaking, the climate of the Continent of Europe is of a dry nature, and porous insulating materials, such as fibre and presspahn, were giving satisfactory results all round. 2. The majority of important supply systems on the Continent are run on the 100-volt basis. It was therefore essential that a meter should not have a higher drop in volts than 0·6 to 1 volt, and furthermore, the authorities responsible for the standardisation of meters were not prepared to allow any higher drop in voltage. After these instruments had proved successful on the Continent, they were imported into this country, and, on the strength of favourable Continental experience, it was not found difficult to effect immediate sales. We know now that the insulating materials above mentioned are of no use whatever in this country. We also know that whilst a commutator, whether of silver or gold, will not appreciably change its surface resistance in a dry atmosphere, it will do so to a considerable extent in a moist and sulphurous atmosphere, and so it happened that these Continental meters developed serious faults. In many cases their insulation broke down after short service, and in most cases the ratio of armature circuit resistance to main shunt resistance changed as the commutator surface became covered with an infinitesimal layer of oxides, sulphides, etc.

The above considerations were taken into account when the company with which I am identified designed the E.A.C. high-torque meter about three years ago, and we realised that if the two sources of trouble above mentioned could be overcome, we should be able to produce a commutator ampere-hour meter, which would not only be a satisfactory instrument, but would offer important advantages over ampere-hour meters of the mercury type, especially for small consumers. The results have so far justified our opinions—over a hundred stations employ the E.A.C. meter, a large proportion of them have used many hundreds for several years, and let it be said that in most cases these meters were observed and tested with greater severity than would have been the case if they had belonged to another type.

By the exclusive employment of pure mica for insulation purposes (except under the commutator) insulation troubles are non-existent in our meter, although a large number of seaside towns have them in continuous use. The commutator segments are built up on a solid ebonite sleeve, and we have yet to hear of a single case of breakdown. Happily for us the prevailing voltages in this country lie between 200–250 volts, and we were thus enabled to employ a higher and more suitable drop in volts. It will be obvious to every one that in a shunted type of meter, in one of the circuits of which there is a point of contact which is liable to change its resistance, the percentage effect of such change of resistance on the accuracy of the instrument is inversely proportional to the drop in volts allowed at full load. Mr. Schattner.

Investigations made by us and confirmed after several years' service by others, prove that the contact resistance between gold brushes and gold commutator will not alter more than 0·1 to 0·2 ohm under the most adverse conditions. We have also been able to construct an armature having as high a resistance as 7·5 ohms, without sacrificing that all-important factor—torque. The maximum error which can occur in the E.A.C. meter owing to change of resistance on the commutator surface is, therefore, not likely to exceed 2½ per cent., whilst it will be obvious that under the same conditions a very much larger error will occur in meters having a correspondingly smaller drop in volts. From the foregoing it should be observed that there is no fundamental reason why the commutator meter should not be entirely satisfactory, and if those engineers who have not had satisfactory experience with this type in the past will take the trouble to investigate the particular merits of the E.A.C. meter, I think they will find my claims founded on fact. The ampere-hour commutator meter has come to stay in this country. The small consumer has also come to stay, and in my opinion a suitably constructed commutator meter, having many turns in the armature circuit, will permanently displace the unipolar mercury meter for small consumers.

Mr. R. AMBERTON (*communicated*): The question of watt-hour meters has already been settled in England, and with a few exceptions the ampere-hour meter is the only type in general use in direct-current stations. As the cost of a watt-hour meter is much greater than that of an ampere-hour meter some considerable advantage would have to be shown to induce central station engineers even to consider the type. There are only two advantages which can be adduced, viz., the possibility of compensating for friction at low loads, and thus improving the accuracy of the meter, and the fact that variations of voltage are taken into account. The accuracy of ampere-hour meters at low loads being in modern meters easily maintained within Board of Trade limits disposes of the first advantage. I believe it is a fact that supply authorities maintain their declared voltage in reasonable accord with Board of Trade requirements; at any rate, the small discrepancies which occur, even presuming that the variations do not average up, are not of sufficient importance to warrant an additional expenditure of several Mr. Amberton.

Mr. Amberton.

pounds per installation. For two- or three-lamp consumers this expenditure would not only be unwarranted but commercially impossible. It is a curious fact that in discussing the question of watt-hour meters *versus* ampere-hour type, it is frequently taken for granted that the wattmeter is a more or less perfect instrument. This is by no means the case. In the United States, trust interests have so far kept the watt-hour meter to the front, and the high prices obtained have enabled these meters to be most carefully constructed. In spite of this the larger stations have found it necessary to bring in every meter once a year for recalibration in order to maintain its accuracy within statutory limits. To sum the matter up, the supply authorities require a reasonably accurate meter at the lowest obtainable price, and at the present time this combination is best obtained with ampere-hour meters. It was with some surprise that I noted the authors' conclusions on the subject of commutator meters. I do not quarrel with their tests on individual meters, but disagree with the deduction that the results given in the paper may be taken as representative of commutator meters in general. They certainly do not apply to the E.A.C. high-torque meter which is made by my company, and which is in extensive use all over the country. The characteristics of these meters enabled them to be guaranteed for $2\frac{1}{2}$ per cent. accuracy from top to $\frac{1}{10}$ load, and for a starting current of 0·5 per cent. There is no difficulty at all in obtaining and maintaining this degree of accuracy. I am in a position to dispute their statement that the commutator meter is gradually going out, or that the mercury type may be justly regarded as the survival of the fittest. As a matter of fact, the enormous and sustained increase in the number of our meters which have been sold would almost justify a contrary assumption. In my opinion the mercury meter has done well in this country, because it was the only type of motor ampere-hour meter manufactured for a long time, and because the only forms of commutator meter which were tried in England for a period of years were manufactured abroad and were not suited to our climate, as mentioned by Mr. Schattner.

I cannot find any mention in the paper of the error in the mercury meter due to variations of temperature. This is surely a very important consideration. According to one of the makers of mercury meters, this error is as much as 0·35 per cent. per °C. variation—in other words, 7 per cent. for 20° C. change in temperature. If one presumes a variation between summer and winter of 30° C., this error assumes the alarming proportions of $10\frac{1}{2}$ per cent.—a greater error than the authors show from all causes in their curve for the commutator meter. The temperature error of the commutator meter of 0·066 per cent. per 1° C. is practically nothing compared to this. The high torque obtainable with commutator meters makes them particularly suitable for small consumers, and the majority of engineers find that quite half of their new consumers have an average load of only two to three lamps, and metallic ones at that. It is obvious that when dealing with such very small currents it is necessary to use

either a watt-hour meter having a shunt coil to compensate for friction, or else an ampere-hour meter of considerably higher torque than can possibly be attained by means of the unipolar mercury disc. The cost of watt-hour meters precludes their use, and there is no way of increasing the torque of a mercury meter except by (1) increasing the strength of the permanent magnets; or (2) decreasing the air-gap. The first has, for mechanical and commercial reasons, its limitations. The second has recently been tried and apparently with disastrous results. In addition, the mercury meter is inherently more expensive to construct than the commutator type. On the other hand, the torque of the commutator meter is ample for the purpose of recording the consumption of the low currents which require to be measured in the small installations in question. I think, therefore, that whilst the mercury meter may continue to be useful in connection with larger consumers, it cannot successfully compete with a suitably constructed commutator meter for small installations. Mr. Amberton.

Professor D. ROBERTSON (*communicated*): The behaviour of meters on rapidly varying loads is an important point on which a few words might be added to supplement the paper. I have recently made a number of experiments on this subject at the Merchant Venturers' Technical College, and have obtained records on meters, substantially correct on steady load, anywhere between one-third and twice what they ought to be, the error in most cases, however, being only a few per cent. The results of the experiments and of a theoretical investigation of the matter are now being prepared for publication, but they may be summarised as follows: A perfect fluid brake meter (*i.e.*, one in which the retarding forces are exactly proportional to the square of the speed) is entirely wrong, and reads high, on variable loads, for it records the R.M.S. instead of the mean value of the load. When the load is switched off, it will take an infinite time to stop, and record an infinite amount while doing so. Actual meters approximating to this type, such as the old Schallenger alternating-current meter with fan brake, and the old Ferranti mercury meter, do not behave quite as badly as this, because the solid friction and the change of law of fluid friction at low speeds cause them to stop in a finite time, but there is no difficulty in devising a load which will make them go twice or thrice as fast as they ought. A pure eddy-brake meter (resisting torque proportional to the speed, and driving torque proportional to the power to be metered) is equally accurate on variable and steady loads whether the inertia be great or small, and whatever the character of the load may be. It will also take an infinite time to stop, but it will only rotate a finite amount while stopping, and that will be exactly equal to the rotation lost by its inertia while it was accelerating. Actual eddy-current meters have also solid, and often some fluid friction as well. The former makes it go slow on fluctuating loads, and the latter makes it fast. The magnitude of either effect depends both on the character of the load and on the inertia of the rotating part, as well as on the amount of the friction. As it increases with the inertia, it is important to keep down the latter Professor Robertson.

Professor Robertson.

as far as possible if there is any appreciable unbalanced friction. Pendulum meters are liable to large errors when the frequency of the load fluctuations is nearly the same as that of the pendulums. Owing, however, to the small damping of the pendulums, this effect is shown on quite a narrow range of frequency, and is not likely to be of any importance in most practical cases. The errors due to the inaccuracy of the pendulums and to neglecting certain small quantities in the theory only cancel exactly when the load is the same in pairs of ten-minute intervals in which one pendulum is alternately accelerated and retarded by the current, but any error due to this not being the case would probably cancel out in the long run, in all ordinary cases. On a cyclic load, however, such as a flashing sign, it is necessary to see that the frequency of the load does not approach that of the pendulums or of the change-over gear. Motor meters having auxiliary parts moved by the main current, such as a rocking brush-holder, are also liable to serious errors when the load fluctuations happen to approach resonance with the moving part. In such cases there is usually a lot of damping, and so the effect is felt over a considerable range of frequency.

Mr. Lawson.

Mr. WALTER LAWSON (*communicated*): General statements against any type of meter, made without the necessary backing of reliable data obtained from carefully compiled records of defects developed under working conditions, are in the main of little use and are frequently misleading. Unfortunately the authors of this paper, notwithstanding their severe criticism of some types, and their marked preference for others, have not supplied such data. Take the case of the electrolytic meter. My own experience with the total-current type (I cannot speak with any certainty of the shunted type) to a large extent refutes the wholesale condemnation expressed by the authors at the outset of their remarks on this class of instrument. Any one familiar with the characteristics and limitations of this meter would not, of course, select it for use on circuits where the maximum load would approach anywhere near its rated capacity. My own practice is to limit its use to loads of 2 amperes and under. Of 800 electrolytic meters installed in Birmingham within the last eight years only 2 per cent. have been returned to the test-room defective. Compare that figure with 8·9 per cent., which is the figure representing the proportion of defective mercury motor ampere-hour meters of the latest types on a total of 2,700 installed during the last four and a half years. An examination of the records shows that the average period of re-setting of each electrolytic meter is three years. As 90 per cent. of these meters read only up to 250 units, it will be easily seen what the class of consumer is for which they have been used. It cannot but be admitted that the use of expensive meters for very small consumers such as these, averaging about 80 units per annum, is undesirable. I estimate the probable saving on the initial outlay is represented by about 10s. per meter, or a total of £400. In view of this and the very small cost of upkeep, together with the immunity from liability to stop registering, it would be interesting

Mr. Lawson.

if the authors could name a type of meter which would have been a better investment, and would have given more all-round satisfaction. That a reliable opinion cannot be formed without the aid of such figures as I have quoted is illustrated by the erroneousness of the general impression respecting the mercury troubles of mercury motor meters. It is very easy to fall into the error of exaggerating this trouble owing to the bad name which some of the earlier types earned for themselves. The necessity of both cleansing the mercury of impurities and of thoroughly protecting the armatures from amalgamation has for some years been fully realised by the manufacturers, so that the more modern types are to a large extent free from this drawback, and what was in some of the older types the most glaring of faults can now be relegated to the minor ones. This fact is clearly shown by the following. Of the total number of defective mercury motor meters of the latest types taken off circuit only 10 per cent. were found to be faulty as a direct result of mercury troubles. This brings me to the authors' remarks on mercury type watt-hour meters. My foregoing remarks will go to prove that the use of mercury, although necessary, is not such a pronounced evil as the authors suppose, and I consequently fail to see why this important meter should have been so peremptorily dismissed. I do not consider my own experience with this meter justifies me in giving a dogmatic opinion on its merits, as it extends over not more than three years and refers only to seven in number; so far, however, they have given no trouble whatsoever. The authors' references to the clock meter are particularly interesting, inasmuch as it is an instrument which comes in for a good deal of both admiration and abuse. The truth is that, whilst we are lured by its theoretical perfection, our suspicions are aroused by the delicacy and complication of its design. Unreliability is the chief charge against this instrument, and it is to be regretted that the authors have not offered the facts on which they base their faith in the contrary view.

In dealing with problems of alternating-current meter testing the authors have done well in pointing out the numerous sources of error that may arise from improper use of the apparatus available. Indeed, the latter half of the paper forms a very valuable contribution to the subject, and the authors deserve praise for the thoroughness of their researches in this direction. After reading this paper, any one responsible for the correct calibration of watt-hour meters of the induction type could not but realise the necessity of seeing that his apparatus is arranged and worked in such a manner as to be absolutely above suspicion. The possible danger of producing a distorted wave in testing operations is, I believe, far more serious as affecting the accuracy of induction meters than any variations of wave-form with which the meters may have to contend under conditions of actual service. The latter, however, is a point for the separate investigation of testing authorities, and is one on which they should satisfy themselves.

Mr. Bertin.

Mr. P. BERTIN (*communicated*): The two curves shown in Fig. 1 of the paper do not favour the commutator meter. It is certainly possible to obtain a commutator meter possessing a much better curve. It may be, however, as suggested by the authors, that the special atmospheric conditions of Manchester are more detrimental to the commutator type of meter, which has given satisfactory results in other towns. It might have been preferable to take the common point of the two curves at half load instead of full load. It is also stated that the speed of the undamped commutator meter is exceptionally high. It would have been interesting to have some of the values of the speed and the corresponding weights of the rotors, without which the indication of the speed value is of little use. It is stated in the paper that the temperature coefficient of a certain direct-current meter is 0·13 per cent. per 1° F., or nearly 0·3 per cent. per 1° C. Now, as far as I could ascertain the temperature coefficient of most mercury meters is about 0·3 per cent. per 1° C. Consequently, a change of 10° C. makes the meter 3 per cent. wrong. The temperature coefficient of most energy meters is from 0·3 to 0·4 per cent. per 1° C.; consequently, a change of 10° C. makes the meter from 3 to 4 per cent. wrong. It follows that if the meters are calibrated on a warm day they favour the consumer, and the supply authorities may lose a considerable percentage of their total revenue. It has been stated that the average temperature of every town is fairly well known. This may be true to a certain extent, and to a small extent only if it is kept in mind that meters are placed either in warm or cold places. But surely the temperature variations in recent years have been very great in England, and still greater in some of the colonial towns. Therefore, if the meters are calibrated at the supposed average temperature (and this entails an extra amount of work for the testing department) it may be assumed that the meters will still be 2 or 3 per cent. wrong for the real average temperature. As suggested by the authors, it would be advisable that meters should be compensated for temperature error to some extent, and this applies both to mercury meters for direct current and to energy meters. It is possible to reduce the temperature coefficient of these meters at least by one-half, and it would be to the advantage both of the supply authorities and the consumers that reduced temperature coefficients should be enforced. I would finally like to mention a point concerning tramcar meters. I believe it is quite possible to make a reliable tramcar meter of the mercury type, or preferably of the commutator type, provided that a sufficient portion of the current is shunted, and provided also that the active part of the meter is properly suspended. This can be done without practically increasing the overall dimensions of the meter, and an air-damping device, if carefully built, will take up all the excessive vibration which, as pointed out by the authors, is so detrimental to the permanent magnets.

Mr. Dawson.

Mr. J. E. DAWSON (*communicated*): I should like to endorse the remarks of the authors with regard to the advisability of systematically

Mr. Dawson.

bringing in all meters to the works after they have been out on circuit five years and thoroughly cleaning, overhauling, and re-testing them before being again fixed out on consumers' premises. There are very few meters indeed that have been out on circuit for this length of time that have not developed during this period some fault or other, the most frequent being such as dirty mechanism, loose contacts, bent spindles, etc., all generally tending to cause the meter to register slow and thus bringing up the item "units unaccounted for" or "units lost in distribution"; and as the authors have pointed out, this may in some instances easily amount to 5 per cent. loss entirely due to defective slow-running meters. The value of this lost energy if capitalised at, say, 5 per cent., would amount to such a respectable figure even in quite small undertakings, as clearly to show that it would pay for the cost of systematic inspection and overhauling many times over and still leave a handsome profit on the credit side of the ledger. The culpable neglect of any attempt at meter testing, etc., is now, I think, confined entirely to the smaller class of supply undertaking, and incidentally it is to be remarked that these are the very undertakings that, as a rule, go in for all the new makes of meters that are put upon the market from time to time, instead of cautiously following the lead and being guided generally by the much more comprehensive and wider experience of the larger undertakings.

With regard to ampere-hour meters of the mercury motor type (page 6) it would be interesting to know if Mr. Ratcliff has evolved any special method of cleansing and purifying the mercury which is taken out of meters that have come in for overhauling, or does he find it cheaper simply to exchange old mercury for new with the meter manufacturers; further, has he found it advisable, when meters come in for overhauling, to enamel all parts that are exposed to the action of the mercury. The authors also state that with the shunted type of mercury motor meter, errors on fluctuating loads may be introduced unless the inductances of the shunt and bath are balanced; this is, I think, a most important point and with large power consumers with rapidly fluctuating loads considerable errors may be thereby introduced. But the difficulty is in checking over these inductances—perhaps the authors will state which method they have found to be the best for doing this. With regard to the satisfactory operation of motor meters generally, on direct-current circuits, do the authors agree with the proposition that the principal determining factor as between one make of meter and another (other things being equal) is the ratio which the driving torque bears to the weight of the revolving element, providing, of course, that both these figures are not beyond a certain limit, either high or low, and also that the ratio of the driving to the frictional retarding torque is fairly high? With reference to electrolytic meters of the Bastian type (pages 9 and 10) the writer has a considerable number of these fixed out on circuit under his supervision on small installations. Some have now been in use over five years, and so far, the expenses in the way of repairs have been very small; the principal

Mr. Dawson.

trouble, however, has been one which I do not remember to have heard of in other districts, and that is a sort of crystallisation taking place at the bottom of the tubes, short-circuiting the plates, and hence cutting out the meter. The writer is inclined to attribute this trouble to the hardness of the water used in this district (about 40 per cent.), but perhaps the authors may have experienced similar troubles, and can possibly give some further information on this point, although I am afraid it is a matter more for the chemist than the engineer. I notice that the authors have omitted all reference to prepayment meters. May I ask if this is significant, or does it merely mean that the authors have not had time to incorporate in the paper details of this type of meter?

Mr. Wright.

Mr. C. H. WRIGHT (*communicated*): The authors have pointed out that permanent magnets can be considerably affected by stray magnetic fields, and it may be of interest to mention the results of certain experiments made some years ago on the permanent magnets used at that time in a particular form of moving-coil instrument, which indicate the necessity of shielding properly the permanent magnets in a meter brake-system. These, as pointed out by the authors, are of more importance as affecting accuracy than in the case of indicating instruments. A magnet arranged with its circuit complete all but the annular air-gap for the moving coil was overwound with a coil so that magnetising or demagnetising ampere-turns could be applied to it, and the flux density in the gap was measured. With this particular form of magnet, which was longer than that commonly used for the brake magnets in some electricity meters, the principal results of the tests are given below:—

Demagnetising Ampere-turns.	Temporary Effect.	Permanent Effect, left after Removal of Demagnetising Ampere-turns.
	Per Cent.	Per Cent.
20	— 0·25	Nil
75	— 1·10	Nil
100	— 1·40	Nil
150	— 2·30	Nil
200	— 3·25	— 0·15
250	— 4·25	— 0·34
300	— 5·25	— 0·40
350	— 6·30	— 0.50
400	— 7·90	— 1·50
450	— 9·60	— 2·30
500	— 11·40	— 3·50
580	— 14·00	— 6·10

When the demagnetising current was reversed so that it had a strengthening effect on the magnet the temporary effect was for 200 ampere-turns + 2·7 per cent., while the permanent effect was only about 0·1 per cent. At 300 ampere-turns the temporary effect was

4·5 per cent., and the permanent effect 0·25 per cent.; and at 640 ampere-turns the temporary effect was 10 per cent., and the permanent effect 1·2. It is thus clear that both a considerable temporary effect and a measurable permanent demagnetising effect may be produced by stray fields under some existing conditions, and that, therefore, shielding of such magnets is important. Efficient shielding is not of necessity obtained by fitting the magnet in any sort of cast-iron box, as some brands of cast iron may get imprinted upon them semi-permanent polarity when subjected to intense local fields, which makes it either a better or worse magnetic shunt to the enclosed magnet than before. On account of the possibility of this more or less permanent effect on some qualities of cast iron, it is safer to employ stout soft-steel shielding completely enclosing the magnet and brake system where strong stray fields are to be expected. If a cast-iron enclosure be properly designed, using suitable metal, and allowing plenty of room inside, it may be made suitable for average cases. Mr. Wright.

Mr. R. H. BARBOUR (*communicated*): As regards the question of direct-current ampere-hour *versus* watt-hour meters, no doubt, for power loads of considerable magnitude there is much to be said for watt-hour meters; but for smaller loads, and especially in the case of lighting, where the voltage is constant within a few per cent., the question is very different. The great bulk of the new consumers of electric light who can come on to the mains in the next few years will be the ones with but few lamps, and those metallic, thus requiring very small currents only. If these consumers are to be made profitable, their cost to the supply authority must be kept low, and their meters, in particular, must be both cheap and reliable. The watt-hour meter is thus out of the question, since it must necessarily be more expensive, as well as less reliable, owing to the presence of a considerable difference of potential between various parts actually in the meter. But besides being cheap, the meter must be accurate on low loads, must start on minute currents, and must require no attention whatever, beyond the periodical readings. The only type fulfilling all these requirements is the commutator ampere-hour meter. Instruments of this type are now available that are accurate below 0·10 ampere, that start below 0·015 ampere, and that are made in a substantial manner with cast-iron cases, and with working parts of non-corrodible materials. Mr. Barbour

The curves given by the authors and purporting to be characteristic of mercury and commutator motor meters need some comment. (1) Any curve for a mercury meter should be plotted with amperes instead of percentages of load as abscissæ; unless this is done, or at least the capacity of the meter mentioned, the curve is meaningless. (2) When two types of meters have curves of different shapes, surely the fair way of comparing them is to calibrate in such a way that each curve shall cut the line of zero error at such points that the average error where fast (between the limits required, say one-tenth and full load, or one-twentieth and full load) shall be equal to the average error where slow. The curve for the commutator meter

Mr. Barbour. would then be plotted rather higher on the scale, so that even the unrepresentative one given by the authors would make a much better showing. (3) The curve given was no doubt obtained largely from meters of foreign manufacture; it certainly bears no relation to up-to-date British practice. (4) The temperature error of commutator meters is negligible, whereas with mercury motor meters a change of a few degrees will make a difference of 5 per cent. or 6 per cent. Thus a line curve hardly represents their performance on consumers' premises,

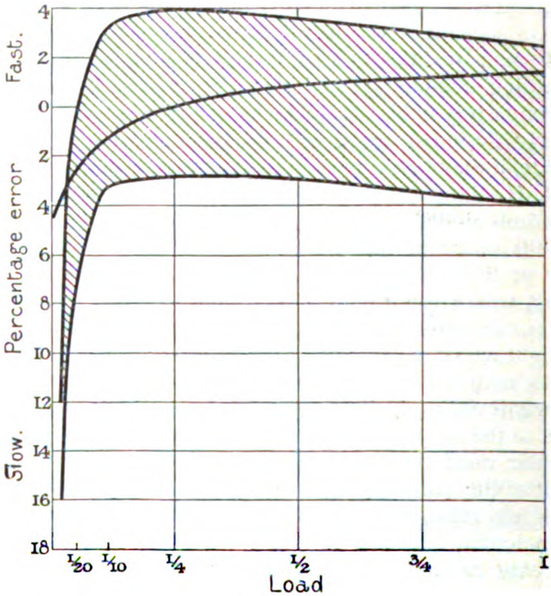


FIG. G.

The band represents the actual performance of Mercury Motor Meters.
The curve is that of a British-made Commutator Meter.
N.B.—The band has been plotted against fractions of the load, merely because it has been taken direct from Messrs. Ratcliff and Moore's paper, which does not mention the actual capacity of the meters.

whatever it may do in the test-room. The proper representation is a band, as in Fig. G, which has been drawn for a variation of 10° C. either way from the normal.

Mr. Sharp. Mr. E. E. SHARP (*communicated*): There are several points in this paper which were not fully touched on in the discussion. First, there is the statement that only watt-hour meters should be legally recognised. This seems to imply the total prohibition of ampere-hour meters, a policy the authors do not endorse by their own practice at Manchester. The only basis there can be for such a suggestion is that supply authorities do not give so much as the declared pressure, as it

cannot be expected that consumers should pay for a higher pressure than their apparatus is designed for. On the next page the authors work out a sum which is based on the assumption that the pressure is always at least 2 per cent. above the declared figure. The fallacy in this is the assumption that "the greatest loss (to the station) is naturally at the time of peak." As a matter of fact, the one time when the volts are most likely to be down on consumers' premises is peak time, due to the greater drop on the mains. In this part of the paper the arguments are those we used to hear ten years ago. Not even watt-hour meter makers would back them up nowadays if they also had ampere-hour meters to sell. In my own experience these arguments have been disproved many times by putting in series watt-hour and ampere-hour meters on various parts of different systems over periods up to twelve months. The readings only showed such small differences as one would expect between any two meters of the same type. The authors' experience with tramcar meters must be very small, as their conclusions are against the weight of evidence that has accumulated during the last three or four years. The use of car meters can hardly be called a controversial question, since the Tramways Union have definitely pronounced in favour of their adoption. Mr. Sharp.

Mr. C. C. PATERSON (*communicated*): I should like to refer to a few points in connection with the testing of single-phase and 3-phase watt-hour meters. First, in relation to the standard wattmeters used for testing these instruments. The authors mention that they have found indicating wattmeters reading low on lagging currents, due to eddy currents in metal parts near to the windings. I can endorse this statement, especially when wattmeters for heavier currents are in question. It is not easy to find precision indicating wattmeters for alternating current, even as low as 400 or 500 amperes, which are accurate at 0·5 power factor. One of the speakers in the discussion has ridiculed the idea of testing the standard wattmeter with an induction meter. This may appear ludicrous, but I know of more than one type of precision high-grade wattmeter whose change of accuracy between unity and 0·5 power factor exceeds that usually met with in induction watt-hour meters. Fig. H represents an extreme case, but it shows the behaviour of an instrument which is frequently regarded as above all suspicion for alternating-current measurements. The diagram shows the change of error in the indications of the instrument as the power factor of the load changes from 0·5 lagging to 0·5 leading current. The volt coil has appreciable inductance, and the wattmeter is also affected by eddy currents in the metal used in its construction. It has several volt ranges, which are varied by putting resistance in series with the volt circuit. On the 50-volt range the inductance effect predominates, and the wattmeter reads high on lagging currents. As more resistance is put in series with the volt circuit, the inductance is more and more swamped and the eddy-current effect predominates, causing low indications with lagging currents. On the 500-volt range, therefore, at 0·5 power factor and 50 cycles the instrument reads 2·3 per cent. low, Mr. Paterson.

Mr. Paterson.

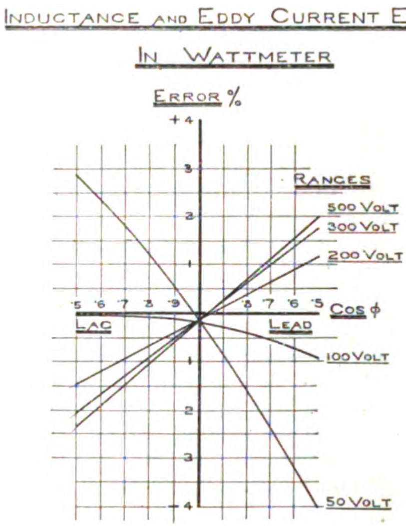


FIG. H.

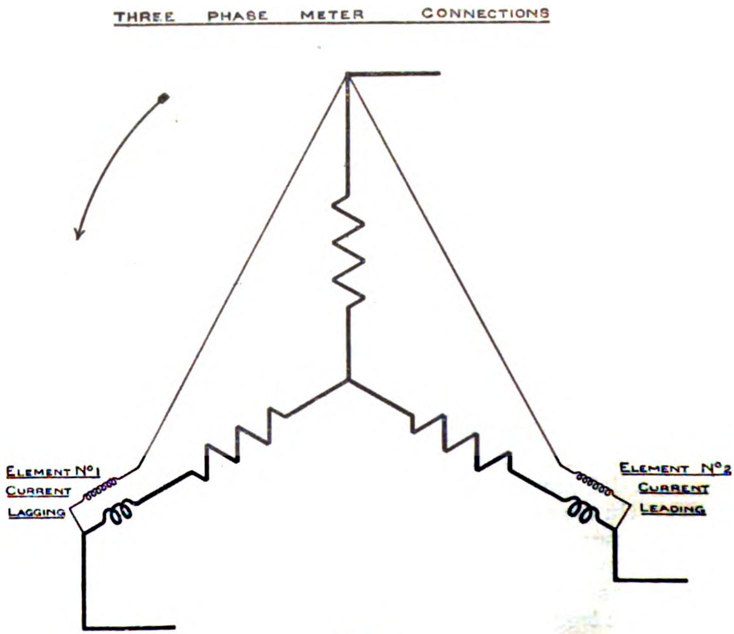


FIG. I.

whilst on the 50 volt-range it reads 3 per cent. high under the same conditions. Mr. Paterson.

Referring now to the testing of 3-phase induction watt-hour meters, the authors show very conclusively that it is inadmissible to test 3-phase meters on single-phase circuits, but they omit, I think, an important factor: not only on account of interaction must these meters not be tested on single-phase circuits, but even if they have been tested on 3-phase circuits it is essential to know which element is to be connected to the leading, and which to the lagging phase of the 3-phase system. Mr. Wild points out that the effect of interaction can be roughly eliminated in a single-phase test by

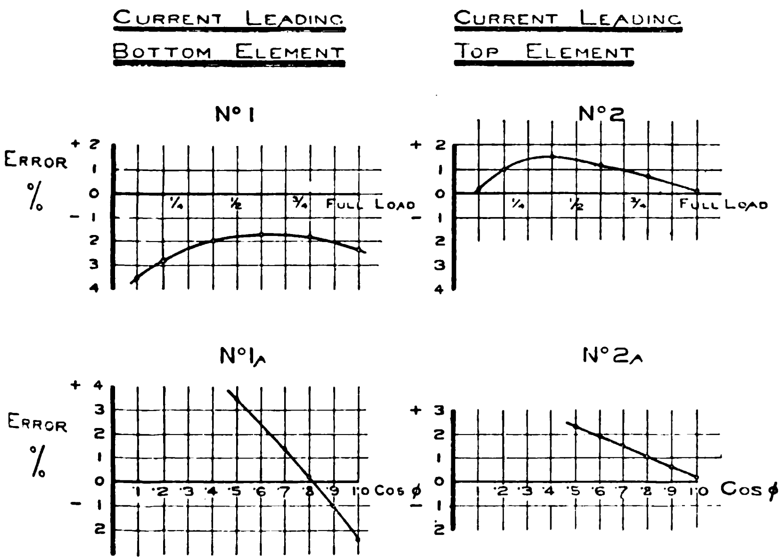


FIG. J.

reversing one of the phases and taking the mean, but this does not get over the main trouble. The point will be made clear by reference to Fig. I, in which the two elements of an induction meter are shown connected to the 3-phase network in the ordinary way. If the system is supposed to rotate in the direction of the arrow and the power factor of the whole system is unity, then it will be seen that in the left-hand element the current in the series coil lags 30° behind that in the volt coil, while in the right-hand element it leads by the same amount. Now, each element has a separate adjustment for power factor which compensates for leading and lagging currents; but since the adjustment is never exact as the meters are turned out of the works, an element will more or less be over- or under-compensated as the

Mr. Paterson.

case may be. If it is under-compensated, it will read low on lagging currents, and the reverse if over-compensated. Thus, it will be seen that if, in Fig. 2, the left-hand element is under-compensated and the right hand over-compensated, the errors will add and the meter will read low. If the elements are interchanged, the errors will again add, but, affecting the rate in the other sense, will cause the meter to register high, although in both cases the power factor of the 3-phase system is unity.

The upper two curves in Fig. J illustrate two load curves of a 400-ampere 3-phase meter with current transformers tested on a 3-phase circuit with phases interchanged. This is not an abnormal case, and it will be seen that there is a difference of over 3 per cent. between the two ways of connecting up the elements. A further difference which exists is shown by the lower curves in which, for each method of connection, the power factor of the 3-phase system has been changed. I have wished to emphasise this point because at the National Physical Laboratory we constantly have 3-phase meters sent to us which have been used on dynamo and steam consumption trials, and the senders have failed to take any precaution to note which was the leading and which the lagging phase of the system to which the meter was connected. Our method at the laboratory is to certify the errors of the meter for both methods of connection, but the whole difficulty would be overcome if meter makers would distinctly mark on the meters which element was to be connected to which phase. If these precautions are taken and meters are tested on 3-phase circuits, our experience is that the 3-phase induction watt-hour meter is as reliable and accurate as any other form of integrating meter. From many tests on both single- and 3-phase circuits, however, we have come to the conclusion that the single-phase test cannot be taken as a guide to the performance of a meter when connected to a 3-phase system, and we never certify on the single-phase test. I disagree with the authors in their opinion that a meter ought not to be considered a 3-phase meter unless it can be tested on a single-phase circuit. Why should a meter be required to comply with conditions which it will never meet with in practice because the testing may be troublesome? As a matter of fact, the testing of 3-phase meters with current transformers on 3-phase circuits at all loads and power factors is a daily occurrence with us at Teddington, and is not attended with the inconveniences which the authors imply.

Mr. Irwin.

Mr. J. T. IRWIN (*communicated*): In their paper the authors bring out many points which are well worth careful consideration, especially as their conclusions are supported by carefully carried out experiments. In considering the effect of a rapidly varying load on shunted ampere-hour mercury type meters it is necessary to divide the meters into two classes; first, those like the Ferranti (old) type where the torque is proportional to the square of the current, and, second, those where the torque is proportional to the current. In the first case, if the ratio L/R in the shunt is equal to L/R in the bath circuit the currents will divide up proportionally to their resistances

and the torque will be proportional to the square of the current in the mains. If the fluctuations of the current are rapid, as for a motor driving a punching machine, then the speed of the meter will not have time to change as the current changes and the meter will have a mean torque proportional to the mean square of the current, and as the voltage is assumed constant it will register proportional to the R.M.S. current. But the power taken from the mains is proportional to the mean current, and if the meter has been calibrated with a steady current the meter will always register too fast by an amount depending on the ratio $C_{R.M.S.}/C_{mean.}$; a ratio that could be theoretically very large, but in quite ordinary cases might give an error of 5 to 10 per cent. If a non-inductive shunt is put across the meter the current from the mains divides between the two circuits; but owing to the induction in the bath circuit and series magnet the variation of current and the ratio $C_{R.M.S.}/C_{mean.}$ is less in the meter than in the shunt, but the mean current in the bath circuit is determined by the ratio of resistances only, so the effect of putting non-inductive shunts across the meter would be to decrease any inaccuracies that might crop up owing to rapid variations of load. In the second class of meter where the torque is proportional to the current, the introduction of inductance into either of the circuits will introduce no error as long as the voltage remains constant, as the current (mean) in each circuit is determined only by the ratio of resistances, and the torque is proportional to the true power. Mr. Irwin

In the latter part of their paper the authors show the effect of wave-form on the reading of an induction meter. These results can be easily explained. The current flowing in an alternating-current circuit and the pressure across it at any instant can be written as follows:—

$$V = v_1 \sin (p\,t) + v_3 \sin (3\,p\,t + a) + v_5 \sin (5\,p\,t + \beta),$$
$$A = A_1 \sin (p\,t + \phi_1) + A_3 \sin (3\,p\,t + \phi_3) + A_5 \sin (5\,p\,t + \phi_5),$$

and the mean power over a complete cycle is equal to—

$$A_1 V_1 \cos \phi_1 + V_3 A_3 \cos (a - \phi_3) + V_5 A_5 \cos (\beta - \phi_5), + \ldots$$

since terms involving different frequencies when multiplied together and integrated give zero value. We, therefore, get the result that the total power is the sum of the powers due to the fundamental 3rd, 5th, 7th . . . waves, each considered separately, and if the reading of a meter is made independent of frequency it will also be independent of wave-form as long as there is no appreciable change in the permeance of the magnetic circuits. We also get the result that, if only the meter reads correctly at one particular frequency and if one of the curves is a sine wave of this frequency, it does not matter how distorted the other is, the meter will still register correctly. That is to say, if the pressure wave-form of an alternating-current system is kept a sine wave, then an induction type meter can be used to register the

Mr. Irwin. energy on very distorted waves of current such as arc-lamp circuits, rectifiers, etc., but this is by no means true where the voltage differs from a sine wave. It would be equally true that for a sine wave of current it would not matter how much the voltage was distorted. In the cases the authors consider, they are dealing with a non-inductive load, and the shape of the wave is the same for both current and pressure. When the harmonic is superimposed on the fundamental the two waves, according to the above equation, could be considered quite separately as giving power to the resistance. Reversing both the current and pressure waves of either component should produce no change in the reading since the power is not altered, and it will be seen in Table II. of their paper that this is practically the case. The reason it is not absolutely true is that the generator giving the fundamental has also a third harmonic, and that this will be added vectorially to the impressed third harmonic due to the second machine, and will not give quite the same value of the third harmonic when the terminals

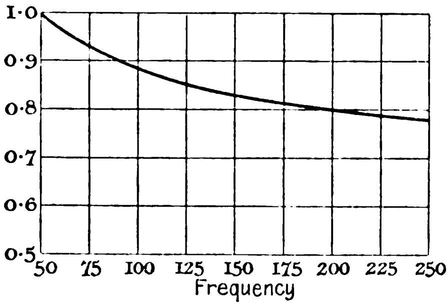


FIG. K.

of the second machine are reversed. It is seen that in practice the meters always read slow, and the higher the value of the harmonic in the resultant wave the slower the meters read. This is undoubtedly due to the fact that they do not register correctly the power given by the higher harmonics. The curve shown in Fig. K was obtained by me for an induction meter, tested on a varying frequency at unity power factor. It shows that a meter which was correct at its normal frequency of 50 was 15 per cent. slow at 150 ∿, and 23 per cent. slow at 250 ∿. Therefore, we can tell at once, if we know the composition of any wave, how much the error in reading will be.

The arrangement the authors adopted in building up their wave was to put two machines in series and to measure the voltage across each machine, the voltage across the two and the wave-form of the resultant on load. It is evident in this case that the composition of the wave cannot be judged by the voltage across each machine, since each machine will act as an inductive resistance to the current sent by the other machine and increase the reading of the voltmeters across each,

Mr. Irwin.

but will decrease the voltage across the two. In this case the only satisfactory way to find the composition of the resultant wave is by analysis. On analysing out wave No. 4 I find the amplitude of the third harmonic to be about 40 per cent. of the fundamental and the fifth harmonic about 10 per cent., and, therefore, according to the above curve the meter should read—

$$\frac{(1\cdot0)^2 + (0\cdot85)(0\cdot4)^2 + (0\cdot77)(0\cdot1)^2}{(1\cdot0)^2 + (0\cdot4)^2 + (0\cdot1)^2}$$

of the true energy—*i.e.*, about 2·3 per cent. slow. This gives about the same value as meter A tested by the authors. The analysis of curve No. 5 gives the third harmonic equal in value to the fundamental, and, therefore, the meter would read—

$$\frac{(1\cdot0)^2 + 0\cdot85\,(1\cdot0)^2}{(1\cdot0)^2 + (1\cdot0)^2} = 0\cdot925$$

of true value, or 7·5 per cent. too slow, which agrees again with meter A. It is inferred from these curves that meters A and B would vary with frequency in about the same way as shown in the curve, but that meters C and D would be largely affected. For the meter tested by me the current in the disc due to the current coil was displaced from the flux in the disc due to the pressure coil at normal frequency by an angle equal to the phase displacement of the current and pressure in the mains—*i.e.*, at zero power factor it did not turn, but as the frequency increased the phase displacement became larger, until at 200 ∿ the phase displacement was 11°, and the flux in the disc was lagging behind the current in the disc.

These results explain why it is that on an inductive load the meter reads more correctly than on unity power factor; because if a large inductance is put in to make the current lag the inductance has three times the impedance to the third harmonic that it has to the fundamental and, in addition, the phase displacement is greater; so the actual power due to the third, fifth, etc., harmonics is very small, and, therefore, the meter will register nearly correctly. The fact that the flux for the harmonics lags in the disc tends to make the meter read too fast for lagging currents and so compensates at some particular power factor for the reduction in flux in the disc. If the current in the meter is leading on the pressure the reverse holds, for not only are the harmonics in the current wave exaggerated, but the meter would not read the total power of these harmonics even at unity power factor. As the frequency increases the flux in the disc due to the pressure coil lags more and more, and therefore for currents leading their pressure waves by nearly 90° the torque will be negative and will oppose the main torque. The effect of this is very evident to distributing engineers, as they very often find that at the sending end of a high-tension underground main where there is a capacity current flowing in to the main the meter reads less than the one at the receiving end by as much as

Mr. Irwin. 10 per cent., and this even when the meters have been carefully calibrated beforehand. The conclusion to be drawn is that each type of meter should be tested at frequencies much higher than those at which it is to be used, and rejected if not up to a definite standard. The standard need not be a very rigid one. A meter as good as meter B would be quite accurate enough for any practical case, whereas meters C and D would be ruled out.

DISCUSSION BEFORE THE MANCHESTER LOCAL SECTION, MARCH 21, 1911.

Mr. North. Mr. G. NORTH: I am glad to see the authors have pointed out that loss due to defective meters is loss of revenue. It is not only loss in generating costs, but it includes the actual standing charges as well. This is a matter which does not in general appear to receive the attention it deserves. Usually, it is far more important to have reliable meters installed than is the mere question of the saving of 2 or 3 watts shunt loss. That relates again to the question of ampere-hour meters as compared with watt-hour meters. Watt-hour meters are generally considered to cause a considerable loss due to their shunt circuits, but the saving due to increased registration at low loads by their use as compared with ampere-hour meters will considerably more than compensate for the shunt loss. With reference to the cramped design in meters mentioned by the authors, I might say I am a meter manufacturer, but have had considerable experience in central station meter testing. I sometimes think it would be a great advantage if central station meter men could change places with the manufacturer. The thing is, the manufacturers have to manufacture meters to sell, hoping to make a certain amount of profit; at the same time, they are asked to give guarantees of accuracy extending over considerable periods, and entailing a certain amount of risk. The manufacturer can, of course, make a good meter, but if submitted to the central station man he would say it was very nice; but when it came to buying such meters at the necessary price asked for, that would be another thing entirely, and a cheap meter would be accepted as "good enough." Manufacturers are more or less compelled to make meters and conduct their business according to prices obtainable, and then try to make the meter as satisfactory as possible under the circumstances. The pendulum meter mentioned in the paper is an example, and is more or less a perfect meter, in certain respects and under certain conditions, but how often is it used as compared with other less perfect types of meter? This simply shows that although we can strive for perfection, the perfect meter will not necessarily be the one actually adopted in practice. With respect to the dynamometer-type meters on alternating current, what the authors say is true; commutator meters of this type can be obtained to give fairly consistent results on alternating current. I have, however, had a good deal of experience with these meters on

alternating current, and I can say safely that they are no good, because the vibration of the moving element, which is fairly heavy, is so great that it wears out the jewels and pivot bearings in a very short time, and that on alternating current the latter will not last one-quarter the length of time that they will on direct-current circuits; this is equally true even if the jewels have spring seatings. Also the question of use with transformers comes in. The high drop on the current coils is another reason why they should not be used with current transformers. With regard to induction meters and driving torque, these do not necessarily need a high torque, because there is no brush friction, as of course that is entirely eliminated, and it is the ratio of driving torque to frictional forces that is important. In my opinion the induction meter is the nearest approach to an ideal meter, and does not require anything like the attention necessary in the commutator type. Referring to the question of wave-form on induction meters, of course it is to be expected that an induction-type meter will be affected by wave-form. It is nothing more in principle than a transformer or an induction meter, having iron magnetic circuits and iron losses, and is sure to be affected by wave-form. The question is, to what extent it is affected, and whether we can keep such effects within practical limits. Much light can be thrown on this, and the results of the authors' tests prove that a sufficient degree of accuracy is obtainable for practical conditions. Mr. North.

As regards polyphase meters, I quite agree with what the authors say regarding the balanced-type of 3-phase meter. I never put the balanced-type meter forward if I can possibly help it, but it is necessary to quote customers for balanced and unbalanced types. The determining factor more often than not is a question of cost, and the mere fact of having a good meter often does not help one. Referring to the forms of balanced-type meters mentioned, I quite agree with what the authors say about No. 7. That is the worst kind of balanced-type meter, and it is almost impossible to check the accuracy. I cannot too strongly condemn the use of that. The one I put forward is that illustrated in Figs. 8 and 9, which I agree is the best form of balanced-type meter. What the authors say with regard to the 3-phase 4-wire meter, Fig. 10, is also true, and I think a greater consideration of this form would have been of interest.

With regard to polyphase meters as affected by interaction, it must be remembered that most polyphase meters have two elements, each with one shunt and two series coils; this is the case with the meter I have in mind and propose to discuss. I have found a slight interaction such as referred to by the authors, and have therefore investigated the matter with a view to discovering the cause and determining the magnitude of the effect. My conclusion is that interaction is due to a small interchange of shunt flux from one element to the other. If the magnetomotive forces of the shunt coils are in the same direction the interaction fluxes add to each other (condition of maximum registration), and if opposite they oppose, and

Mr. North. neutralise each other if equal (condition of minimum registration). This conclusion is confirmed by the results of the authors' tests as shown in Fig. 21, because by a progressive shifting of phase of the current applied to one element the resulting curve would be a sine function. On this assumption the effect of interaction can be mathematically expressed and completely determined for the case when the meter is used on 3-phase circuits. I have, therefore, worked this out and find the general expression for error due to interaction in a polyphase meter on a 3-phase circuit to be:—

$$k \cdot \frac{3\, i_3 e_3}{i_1 E_1 + i_2 E_2},$$

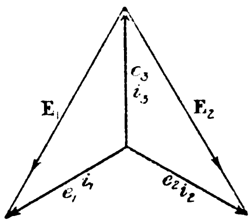


FIG. L.

i_1, E_1 being respectively the current and voltage applied to one element of the meter.

i_2, E_2 being respectively the current and voltage applied to the other element of the meter.

i_3, e_3 being respectively the current and voltage of the third phase of the circuit.

k being a fraction representing the interchange flux due to *each* element of the meter, expressed as a proportion of the impressed voltage.

On single-phase, therefore, the difference of error between the condition of helping and condition of opposing fluxes would be $2k$. On 3-phase balanced load it will be seen that the value of the above expression reduces to k, that is to say, the error on 3-phase is only half that obtained on single-phase. It is to be observed that the values expressed in the above formula represent instantaneous values of current and volts, so that the formula is perfectly general and gives the true error due to interaction whatever the power factor or other condition of the circuit. By carrying this principle further and applying it to unbalanced load circuits, it can be shown that even under the most extreme conditions of unbalanced load and low power factors the error still remains very small. This matter summed up, therefore, amounts to this, that with a difference of error on single-phase not exceeding 3 per cent., that is, a value of $k = 1{\cdot}5$ per cent., and assuming the meter adjusted to the mean of this error, the actual error on 3-phase, even under the most extreme conditions of power factor or unbalance found in practice, will be within 1 per cent., which is certainly satisfactory so far as all practical requirements

are concerned. I would point out that interaction may be greater on one element than the other, which would, of course, mean a slight modification of my theory, but in any case it will not be difficult to determine what it is by means of the single-phase test. The conclusion is, that though interaction may occur in a polyphase meter, it is permissible if it does not exceed certain prescribed limits; that it may be completely determined and due allowance made on the single-phase calibration, resulting in a negligible error on 3-phase, so far as all practical purposes are concerned. It is therefore my opinion that, given a reliable meter, the polyphase meter is the best, most practical, and most accurate method of measuring the energy delivered to a polyphase circuit. I emphasize this, because although the authors do not directly say so, the impression is created that polyphase measurements are inaccurate and unreliable, whereas such is not the case. It may be conceded, on an experimental basis, that the polyphase meter is not capable of quite the degree of accuracy as the single-phase meter, but in actual practice they are about equal. Certainly the polyphase meter is better and more accurate than the use of two single-phase meters, or three single-phase meters with potential circuits connected in star, unless the neutral-point of the circuit is available. Both these methods are open to objections and inaccuracies greater than is the case with the polyphase meter. If the neutral-point of the circuit is available, and three single-phase meters are employed, it then becomes simply equivalent to three single-phase circuits. I would, in conclusion, point out a practical drawback to the use of either two or three single-phase meters on a polyphase circuit from the central station meter man's point of view, which is that the registration on the two or three meters, as the case may be, will not be the same; and it is very difficult to convince consumers that this is how it should be—that the readings should be added together and that the higher-reading meter is not over-registering. Mr. North.

Mr. H. E. TRENT: By using instruments and meters in positions for which they are unsuitable many errors may be manifested, and there is no doubt that the users are largely responsible for such errors. Instruments or meters may be efficiently shielded against stray magnetic fields, but are not therefore proof against any magnetic field; just as the manufacturers state that the instruments have a negligible temperature error, but if the apparatus is used, say, on a furnace door, the manufacturers' liability ceases, or should do. I heard a short time ago of a station which had its voltmeter in close proximity to the busbars, and when the machines were started up the volts indicated were 600; upon the load increasing the volts indicated were about 300. It would be a most difficult problem to design an instrument to take care of the abnormal, especially at the low prices which reign to-day. There is a lack of standard specifications to guide manufacturer and user in getting the best results from this class of apparatus. Fig. 11 is really remarkable. showing as it does the errors which are no doubt due to the abnormal Mr. Trent.

Mr. Trent. position of the instruments in relation to the busbars, and it would be of interest to know the exact conditions. On page 12 the authors refer to the removable spindle tip; this design has been in common practice for many years, and it is most necessary where a pointed pivot and not a spherical-ended pivot is used. The ball bearing is an additional complication which in practice may prove no better than the steel pivot in minimising friction, as it is necessary to have two jewels, one fastened to the shaft of the meter and the other forming the bearing. To minimise friction one firm is now using a diamond bearing. The cramped design to which the authors refer is purely a matter of price.

Mr. Jepson. Mr. A. E. JEPSON: I am in thorough agreement with most of the remarks in the paper: there are, however, one or two points which might be emphasized. On page 4 reference is made to meters for large power consumers. There is no doubt it is of very great importance where thousands of units per annum are being registered to have them registered accurately, as an error of 1 per cent. very soon pays for the cost of the meter, and many manufacturers and tramway managers consider it worth while having a check meter for this reason. The question of the use of watt-hour and ampere-hour meters, and the various losses in the two, is a very important one. If the voltage is slightly above normal, the loss accruing in a very short time is very much more than would pay for the extra cost for the watt-hour meters. Watt-hour meters nowadays can be bought for a very few shillings more than ampere-hour meters, and it might be well worth while in some cases to use these. On page 6, referring to mercury meters, mention is made of a black powder (which is not dirt) found in the mercury chambers of certain meters. Apparently this is pure mercury, because if this powder is put into a very weak solution of sulphuric acid it coalesces. It was thought at one time that it was an oxide, but I think that rather upsets the theory. It also occurred to me that this might alter the resistance of the path in a shunted meter. This is a point which is well worth investigating, as under certain conditions of load, etc., a considerable amount of this powder is formed. With reference to the commutator-type ampere-hour meters mentioned on page 7, I think that to a great extent many of the defects found in these meters is due to their quality. There is, however, one advantage about this type of meter, and it is that the repairs are very simple, when the meters are well made.

On page 8 it is stated that "the damped type of meter has a more moderate speed than the undamped type, but required a higher working voltage across the armature." I do not think that it should require a higher working voltage, and should be glad if the authors would deal with that point. On page 12 reference is made to bearing troubles. It is essential that bearings should be well made. Another essential is that the jewel should be put on some form of spring, as I think this saves a considerable amount of breaking of jewels.

Very great care should be taken in the seating of jewels, because if a very wide temperature change takes place in the seating, it must crack the jewel if not well set. On page 13 mention is made of the astatic properties of the clock-type meter, and Mr. Ratcliff will probably remember taking a test for this with an electromagnet. I think it had 4,500 ampere-turns and an iron core, and it was found that it had no appreciable effect, although placed directly under one pendulum. Also on page 13 the authors state "testing is difficult and tedious, and it is impossible to make a rapid time test at any particular load." The length of test, I think, is really not so important, as a dial test should always be taken on any meter, and this is only what has to be done with an Aron meter for one test; or at the most only two tests, one on a high load and the other on a low load, need be taken. Mr. Jepson.

With reference to the following sentence on page 14, "Poor insulation of the commutator; this occasionally results in carbonisation, and partial shunting of the pendulum coils, the meter then registering slow," I think this has been found to be more often than not due to the collection of dirt between the commutator sections, and it can easily be removed; in any case, it is a very rare occurrence. Again, with reference to the "Pitting of the pendulum arbor pivots," no doubt the authors will not have found this on meters made during the last few years, as this trouble, which could only be found after a long time, has been remedied by the use of a stabilit absolutely free from acids. I think the authors have not made any mention with regard to the testing of meters at a certain temperature, and this is rather important, for the usual temperature of 60° F. is too high. On page 15 it states, "The possibility of error due to the various contacts in the pendulum circuit working loose," as being one of the drawbacks, but this is now got over by soldering all the connections in the shunted circuit. Speaking of tramcar meters of the mercury type, the authors mention the cushioning effect of the mercury, but I think there is an equal hammering effect due to the mercury above the disc in the mercury chambers.

Mr. W. GRANT: The bulk of my remarks will be confined to direct-current meters. Referring to page 5, where the losses in watt-hour and ampere-hour meters are compared to the advantage of the watt-hour meter, I would make the following criticism: A consumer on a lighting circuit is supplied at a definite declared pressure, and if this pressure rises above the normal, I do not see that the supply authority can legitimately charge for the excess units due to this rise. Also if the pressure does rise, the current increases, and the consumer pays for this excess current which he does not want, whilst his lamps are overrun, and their life shortened. In regard to the amalgamation troubles mentioned on page 6, I can well remember this from personal experience. I would like to ask the authors if they ever had a case of the mercury being ejected from a meter when a short circuit took place. I can also corroborate the authors' remarks on page 7 about total-cur- Mr. Grant.

Mr. Grant. rent meters of the ampere-hour type. These meters get very hot, and are extremely heavy. Then the commutator-type ampere-hour meters are, as the authors remark, very flimsy. I can remember a curious case of interaction with meters of this class. These meters were unprotected from external fields. Now, as a rule, a considerable number of meters, on coming from the manufacturer, are found to be correct on being tested by the supply authority. Those to which I refer were hung up close together, and back to back, and they were all found to be too fast. They were all readjusted and passed into the store. Then one of them was sent out as a check on another meter, and ultimately both were brought in and re-tested, when the old meter was found to be correct, and the check meter incorrect. This drew our attention to the trouble, which was, of course, due to the leakage from one meter to the other, and the consequent weakening of the field. I am also in agreement with the authors in their remarks on the electrolytic meter. The destruction of the record with this class of meter is a great fault, as these meters require to be re-set periodically. Then testing them is a very tedious business, whilst in one make the excessive voltage drop and the impossibility of reading it when the current is passing through it, due to foaming and the artificial raising of the level, militate against it. Also I am of the opinion that the layer of oil used on the surface does not completely stop evaporation. Crystallisation is also apt to take place with the shunted type. In regard to meters for polyphase circuits, I believe that one firm in this country recommend the use of two separate meters for this work, so they may have found out the interaction troubles mentioned by the authors.

Mr. Cunliffe. Mr. R. G. CUNLIFFE: I notice that the authors speak rather badly of ampere-hour meters for tramcars. I might say that in Manchester we are using ampere-hour meters in tramcars with perfect success. We have about twenty in use, and the results are quite satisfactory. The great fault with these meters for tramcar use is, in my opinion, due to dirt getting into them. Troubles due to vibration have now been largely overcome. I wish the authors had included time devices within the scope of their paper, because they depend for their operation on the same properties as the electricity meters. The motor portions of certain time meters are, moreover, of extremely interesting design, and as such meters are largely used on the Continent, and are coming into use on many of our own tramway systems, I have no doubt that useful information, especially to manufacturers, will be forthcoming at this discussion.

Mr. Shaw. Mr. W. B. SHAW: With regard to the two single-phase meters, I would like to ask whether, if these were tested and found accurate on unity power factor, it is probable that when put on induction load with an average power factor of, say, 0·8, an error may be expected in the reading? I am glad to notice that the authors regard the two single-phase instruments with favour when comparing them with the combination instrument, because it seems to me, particularly with regard to switchboard work, that there are so many advantages with the two in-

struments that they are well worth the extra cost. The ratio of the two instruments, depending as it does on the average power factor, which in most cases is a reasonably constant quantity or only a gradually changing one, gives a pretty accurate indication of the correctness of the instruments. Any change in its value, due to one of the instruments getting out of order, is readily noticeable on the log sheet, and attention is therefore drawn to the faulty instrument before much error has crept into the record. In addition to this, as the ratio of what its record ought to have been to that of the other instrument is known with a fair degree of accuracy, a correction could easily be made from the reading of the good instrument. With two instruments it is easy to obtain the average power factor over any period from the ratio of the readings, or at any moment by taking the ratio of the speeds of revolution, and using the well-known curve or formula. It is thus a very simple matter to check the wattmeters against the ammeters and voltmeters on the board, so that the accuracy of all the instruments can be carefully and regularly watched with little trouble. Mr. Shaw.

Mr. L. C. BENTON: From Mr. Shaw's remarks he would seem to be under the impression that the authors are in favour of the metering of polyphase circuits by two separate single-phase meters rather than by a two-meter combination polyphase meter. On the contrary, however, I understand that the authors decidedly recommend the use of polyphase meters, and I would like their confirmation of this. The authors state it is their opinion that no stone should be left unturned by the manufacturers until meters can be guaranteed correct within 1 per cent. under all ordinary conditions of service. In my opinion, it is more desirable for the standardising laboratories to be first in a position to agree with each other within 1 per cent. before manufacturers can be expected to go to the expense of attaining to the high degree of accuracy in commercial meters desired by the authors. The various standardising laboratories agree fairly well in their tests on meters of small capacities on non-inductive loads, but they are by no means in close agreement in tests on large-capacity meters, especially on inductive loads, which, owing to the large consumptions they register, are the ones on which the most accurate checks are required. Mr. Benton.

Mr. W. CRAMP: Although I have little experience in the practical testing of meters, I feel that there are certain points not fully elaborated by the authors upon which I should like some further information. The first of these is involved in the question of reversibility. It sometimes happens that for test purposes arrangements are made by which power is put back into the mains through a meter. The latter is then obliged to work in both directions, but I have generally found that there is a considerable error in one direction or the other. Have the authors made any tests for accuracy when reversed? It also seems to me that there may be some tendency among electrical engineers to strain after too much accuracy; not that I think a meter can be too accurate, but simply that obtaining the last ½ per cent. may cost too much. After all, we have to remember that the accuracy Mr. Cramp

Mr. Cramp. of electricity meters is already far in advance of anything met with in the gas world.

There have been complaints during the course of the discussion on the part of the manufacturer, particularly with reference to price. In the paper it is clearly shown that the Aron meter is, on the whole, more accurate than most other forms, and is less liable to variation. The meter is also one of the most expensive to make, and has required an exceptional amount of skill and ingenuity in design, yet for central station work I think there is not 10 per cent. difference in price between this meter and the ordinary motor meter. It is difficult, therefore, to see where the justification for the manufacturer's complaint lies, especially if he happens to be making anything but the Aron meter. It seems almost hopeless to expect alternating-current meters to be very accurate, since not only has phase-difference and wave-form to be taken into consideration, but the whole meter depends for its action upon the relationship between resistances and reactances. It is almost impossible to calculate the latter exactly, and neither quantity is constant under different conditions of temperature, current, etc. Apart from this, it seems in the paper that wave-form, unless very exaggerated, does not cause great errors in most meters, and the error of 27 per cent. shown in one case would never, I think, arise in practice. Another point upon which the authors have not touched is the test for immediate starting and stopping, which seems to me extremely important. Perhaps they will add a few words giving their experience of this. As regards the question of stray field, it has always been a wonder to me that manufacturers do not construct their permanent magnets in such a shape that the yoke of the magnet would shield the poles. This would largely avoid the errors at present existing. Finally, I think the reason for the accuracy of the Aron meter under very varied conditions is largely, if not entirely, due to the fact that the timing mechanism is driven independently of that mechanism which registers the energy, or rather that variations in the energy are only arranged to cause a variation in a time mechanism which is independently driven, while in the ordinary motor meter the timing and metering have to be carried out by the same torque.

Messrs. Ratcliff & Moore. Messrs. H. A. RATCLIFF and A. E. MOORE (*in reply*): Mr. Holden's remarks with regard to shunting mercury meters, are, to a great extent, in agreement with our own opinions, but he surely does not think that we would seriously suggest the use of 1,000-ampere unshunted-type mercury meters. We rather questioned the wisdom of using mercury meters at all for such large current capacities. The mercury watt-hour meters referred to in the paper were probably not of the latest types, and as Mr. Holden states that improvements have been made, the defects in the earlier models have, presumably, been recognised. We cannot agree with him that change in mercury resistance is of no consequence in the case of the watt-hour meter to which he refers. The potential difference across the shunt is only 0·1 volt, and the armature circuit current is about 50 amperes; as this corresponds to a resistance

Messrs. Ratcliff & Moore.

of only 0·002 ohm, it is obvious that as mercury is about 60 times the resistance of copper, the mercury must form an appreciable portion of the total resistance of armature circuit, and therefore any change in its resistance will affect the accuracy of the meter. As a matter of fact, our own experience has shown that a slight difference in the quantity or quality of the mercury does affect the accuracy of the watt-hour type of meter.

As regards tramcar meters, it is obvious that we practically recommended the mercury motor type for this purpose, but at the same time mentioned the severe conditions which they had to withstand, and the resulting acceleration of certain troubles. The conditions on a tramcar are probably at least five times as severe as ordinary house service conditions, and we therefore consider that twelve months is about the average time limit of accurate working, but if low-load accuracy is of no importance, and rather wider limits of error are permissible at the higher loads, then this period may be extended. Although outside the scope of this paper, we would inform Mr. Holden that the controversial nature of the question of material benefits derived from the use of car meters, was gathered from numerous articles and correspondence in the technical press.

Both Mr. Holden and Mr. Cunliffe remark that the use of meters is productive of good results, but Mr. Cunliffe states that equally good results were also obtained by the use of time meters, and, moreover, the good results obtained with the electricity meters, were in spite of the considerable inaccuracies of the meters used, as shown by our own tests on his meters. It would appear, therefore, that almost any form of indicator capable of giving a comparison as between car and car, has a beneficial result, presumably due to a moral effect on the drivers. The time meters referred to by Mr. Cunliffe are in no sense electricity meters, and are, therefore, quite outside the scope of this paper. Mr. Holden's remarks with regard to the saving of brake shoes are very interesting, and no doubt quite correct, since it is reasonable to suppose that the use of meters on cars will tend to encourage coasting.

Mr. Melsom refers to the temperature coefficients of meters; this is certainly a very large subject, and one which we could only just touch upon within the limits of the paper. We have had a very considerable experience of quite unsuspected temperature effects in many different types of meters, and can fully confirm the very interesting curves which he has produced. We emphasised the effects of bad contacts because the heating effect due to contact resistance is not likely to be a constant one, and, in certain cases, the heating from the bad contacts may be greater than that due to the resistance of the coils. Mr. Melsom's curves show the difference between the accuracy curves of a meter before and after a six hours' full-load run; both these are probably outside ordinary working conditions. We usually strike a sort of average by leaving the meter running for one or two hours at full load before testing, and in the case of watt-hour meters, the pressure circuits are switched on at least six hours before testing.

Messrs. Ratcliff & Moore.

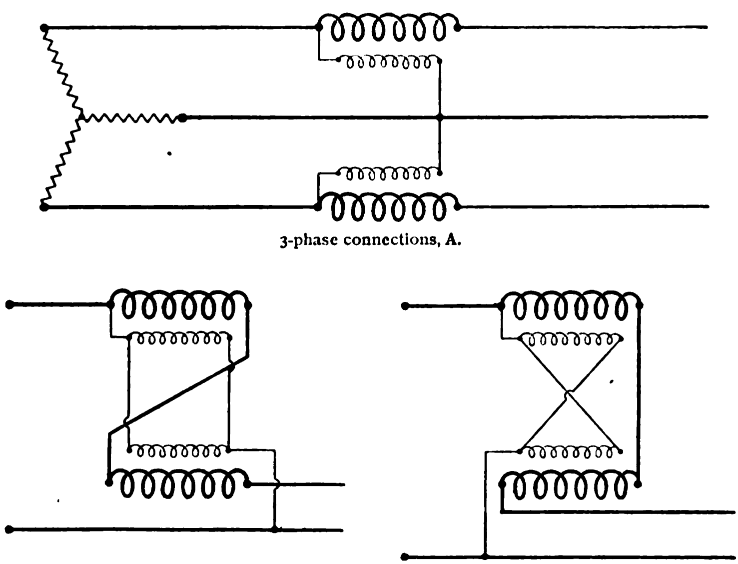
With regard to the two curves shown in Fig. 1, the curve for the commutator type of meter was drawn from the average of results obtained on a number of meters, all of which were either new, or had merely been running for a few months in the test-room, but in no case had they been out on circuit. The curve for the mercury meter was based on average results obtained from tests on new, off-circuit, and repaired meters. The sizes in both cases were either 2½, 3, or 5 ampere. Mr. Melsom's results for the commutator type of ampere-hour meter fully confirm our own; it is almost impossible to obtain the same results two days on running, and the accuracy curve falls off very much after the meters have been in use for a short time. The 2 watts loss per 100 volts in the shunt coils of watt-hour meters is a very usual allowance, and most of the well-known makers are prepared to meet this requirement.

Mr. Garton's remarks with regard to electrolytically pure copper and mercury are very interesting, and if time and experience with the meters confirm his statement, then the particular type of meter to which he refers should become a very reliable one. The initial accuracy of this type is at present very remarkable. We do not condemn the induction type of meter, and, in fact, actually recommend it for certain conditions, but we make the important proviso that it should be practically unaffected by changes in wave-form. Mr. Garton questions the need for higher torque in the case of induction meters, but it is nevertheless a fact, as we stated, that most of the well-known makers are now selling so-called high-torque meters. Torque should certainly not be increased by increasing the weight of the rotating portions, and this point is referred to in the paper. His remarks with regard to the shunted dynamometer type are very interesting, and confirm our own suggestions; his experience with polyphase meters also emphasises the desirability of using unbalanced type meters. In the case of the small mercury ampere-hour meters referred to, there is usually a considerable amount of resistance in series with the bath, and in this case there is not the same likelihood of troubles and inaccuracies due to change in the mercury resistance.

Mr. Wild says that in his tests he expected that it was the amplitude of the harmonics which was going to affect the accuracy, and that the meters would run too fast. We expected very much the same thing, but found that whilst the amplitude of the harmonics does apparently affect the accuracy, all the meters run too slow. We agree that it is difficult to designate any of the waves shown in Fig. 19 as flat-topped. We had intended to determine the form-factors and amplitude-factors of the waves, adopting Mr. Wild's method, but found we had insufficient time. With regard to polyphase meters, reference to Table III. shows the effect of reversing one element, but we have found generally, that if a polyphase meter be connected up in the three ways shown in Fig. L, better agreement of results is obtained with connections A and B than with A and C. The effect to which he refers in connection with the use of current transformers is very familiar to us, and

he is quite right in fixing it as one of the objections to testing meters without their transformers. Messrs. Ratcliff & Moore.

Mr. Edgcumbe questions the method recommended for making the quadrature adjustment in induction type meters, but in practice we have found it to be the most reliable method, and also a comparatively quick one. He may perhaps be surprised to hear that the phase error in an induction meter is frequently less than in many of the so-called standard wattmeters. As regards his suggestion for the use of a power-factor meter, it should be noted that we have recommended testing alternating-current meters on single-phase circuits, but so far we



3-phase connections, A.

Single-phase connections, B.

Single-phase connections, C.

FIG. L.

have not been able to obtain a reliable single-phase power-factor meter, or phase meter. The distortion of most of the waves shown in Fig. 19 is, as stated in the paper, probably abnormal, compared with the waves obtained from modern generators. We may say that of meters A, B, C, and D, the quadrature is in every case adjusted by a short-circuited winding on the volt magnet.

Mr. Baker's remarks fully bear out our experience. He remarks that we say nothing about our experience with "off-circuit" meters; to give statistical details of this branch of the subject would constitute a paper in itself, but much of the critical matter in the present paper is based on a long and extensive experience with "off-circuit" meters.

Mr. Trotter appears to think that we condemn the use of ampere-

Messrs. Ratcliff & Moore.

hour meters, whereas this is by no means the case, and in addition to commending certain well-known types, we also point out the advantages of ampere-hour meters. What we do object to is the use of ampere-hour meters for the measurement of electrical *energy;* by all means let them be used for measuring what the lawyers call, and what no one else calls "the quantity contained in the supply," but let the distinction be clearly recognised. With regard to the two curves in Fig. 1, the curve for the commutator meter is a comparatively good one, and it is quite a usual thing to obtain much worse results, as has been amply confirmed by several speakers. As regards the repairing of meters, in the case of a large supply authority possessing a fully equipped repair shop, repairs are both legitimate and satisfactory, but even in the case of smaller electricity departments, it is essential that the cost of repairs should not be excessive, even when undertaken by the manufacturers. Unfortunately, with electrolytic meters this is the case. As regards commutators, it is certainly true that the frictional torque is reduced when the diameter is small, but unfortunately this advantage is frequently outweighed by the attendant constructional defects.

Mr. Trotter condemns our ideal limit of permissible error, but we may say that our experience has shown 1·5 per cent. to be quite easily obtainable at the present time, down to as low as $\frac{1}{10}$th load on most good direct-current meters, and we do not anticipate any trouble in eventually obtaining 1 per cent., and it will no doubt be possible to obtain a similar figure for single-phase alternating-current meters. We do not imply that the present legal limits are retrograde, but suggest that any attempt to extend them would be a retrograde step. We know that many importers of Continental meters have been anxious to get the limits of permissible error extended, and letters have actually appeared in the technical press in support of this suggestion. Mr. Trotter suggests that the voltage drop in small watt-hour meters would be excessive, but as a matter of fact it certainly need not exceed the limits which are regarded as permissible in the case of motor and electrolytic ampere-hour meters.

Mr. Evershed's interesting formula for the law of the commutator type ampere-hour meter is a mathematical alternative to the statement made in the paper, that the theory of this meter is based on the law of a perfect motor. His concluding remarks with regard to cheap meters and loss of revenue, are very pertinent.

We are glad that Mr. Rayner has pointed out the errors likely to be introduced by leakage when using the potentiometer for the measurement of high potential differences, and to the false deflection due to electrostatic attraction between the movable and fixed parts of the galvanometer. This latter trouble is common in a greater or lesser degree to most forms of indicating instruments, but it is not always taken care of. We quite agree with his suggestion that meters intended for use on important tests should always be standardised both before and after the test. We always adopt this practice, and, moreover,

Messrs. Ratcliff & Moore.

endeavour to test the meters as nearly as possible under actual conditions of loading, power factor, and connections, etc. We agree that it is easier to adjust and accurately standardise two separate single-phase meters than it is a polyphase one. In cases where integrating meters are used for important steam consumption, or efficiency tests on polyphase generators, and where it is required to know very accurately the errors of the meters at definite specified loads and power factors, two separate single-phase meters can be tested with greater precision, and the results relied upon to a higher degree of accuracy than is the case with a polyphase meter. For service and switchboard conditions where the average accuracy of the meters is of importance, a good polyphase meter is probably better than two separate single-phase meters, and also has the further advantage of simplicity of readings. We have not attempted to define the complex quantity known as the "power factor" of a circuit, but for convenience have adopted the ratio (watts)/(volt-amperes) as a basis of comparison. Mr. Rayner's suggestion is a very good one, and he also confirms our own opinions as regards relying on the readings of the wattmeters only as being of real importance.

We cannot agree with Mr. Fawssett's suggestions regarding the testing of large power consumers' meters *in sitû*, as we consider that the less there is of this done the better. Our case for watt-hour meters was admittedly favourable, but we allowed a wide margin for discrepancies; our main object was to kill the "shunt loss bogey." Good watt-hour meters could be made at a reasonable price, and should possess a high degree of accuracy. The method suggested for testing large meters without their current transformers is very unreliable, and we would emphasise the fact that this should never be done unless absolutely unavoidable. If wattmeters are available for testing transformer ratios, why not test the meters directly in conjunction with their current transformers? As regards interaction in polyphase meters, we may state that many other arrangements than those given in the paper have been tried, but all the results point to a common cause. From the description of his tests we should imagine that Mr. Fawssett had not succeeded in detecting the magnetic interaction effect, but had merely discovered the compound braking effect. Mr. Fawssett's apologetics on behalf of the mercury watt-hour meter confirm our own opinion of it. The 10 gramme-centimetre torque meter he speaks of has only been on the market a few months. Nearly all the manufacturers have realised that their original induction meters had torques which were too low for permanent reliability.

Mr. Young's mathematics prove the case, but the particular paragraph to which he refers was misplaced in the final editing and arranging of the paper. It should have applied to watt-hour meters only, in which case, of course, errors may be introduced if the voltage fluctuates. There is no appreciable error in ampere-hour meters other than those following a square law, but this type is now quite extinct.

Mr. Schattner fully confirms all we have said with regard to the

Messrs. Ratcliff & Moore.

commutator type of ampere-hour meter, as practically all the samples tested were of Continental manufacture. The fact that other makers of this type of meter are now selling mercury meters, also appears to confirm the opinions expressed in the paper, quite apart from information given in several valuable contributions to the discussion.

We quite agree with Mr. Lawson's first remark, and for this reason all our expressions of opinion, favourable or otherwise, were based on the results of actual experience. To have given statistics would obviously have been impossible in a paper of reasonable proportions, quite apart from the fact of its being unnecessary. We cannot see that Mr. Lawson's remarks regarding a certain type of electrolytic meter in any way refute the accuracy of our general statements. We did not condemn any particular type. As regards mercury ampere-hour meters, we described them as the survival of the fittest, but referred to the inherent disadvantages of mercury. Mercury appears to be a necessity in successful ampere-hour meters, but in the case of watt-hour meters there are many alternatives, and for this reason alone we should not encourage its use, quite apart from our experience of other incidental troubles.

Mr. Bertin refers to the question of temperature errors. These are well-recognised and fairly extensive errors, but they may be reduced to a certain extent by calibrating the meters to an average temperature. When quality is regarded as of more importance than the question of price, the manufacturers may perhaps see their way to reduce these errors, as the problem is by no means a difficult one.

In reply to Mr. Dawson, we may say that in the works with which one of us is connected, we clean all our own mercury, and find it much cheaper than changing it for new mercury. The process is a continuous and automatic one; the mercury after a preliminary mechanical filtering is passed through a series of vessels containing dilute nitric acid, and water. Beyond a few samples we have had no experience with prepayment meters.

Mr. Wright's figures are very interesting. It should be particularly noted that the experiment which he cites refers to a magnet longer than those usually employed in meters, and hence, presumably, more stable; and also that, as a rule, the variation in the calibration of a meter is proportional to the variation in the square of the magnet strength.

Mr. Barbour's remarks endorse the practice in Manchester of using ampere-hour meters for small consumers, and watt-hour meters for large ones. We have not found the temperature errors of commutator type ampere-hour meters to be negligible, and we are at present experimenting with a view to defining these errors.

Mr. Sharp's points are mainly answered by the replies to other speakers. The Tramway Union have pronounced in favour of car meters only since the writing of the paragraph referred to, but information which has recently appeared in the technical press would appear to confirm the statement made in the paragraph in question.

Mr. Paterson's explanation of the method adopted for testing a

3-phase meter confirms our opinion that a meter cannot be regarded as a true polyphase meter of the unbalanced type, unless it is capable of being accurately tested on a single-phase circuit. We are thoroughly familiar with the points which he raises, and, in special cases, have tested meters in the same manner. In the case of meters used as checks on steam-consumption tests, etc., where, presumably, all the conditions of the load and circuit are known, such a test is probably quite correct; but for ordinary service work the conditions of the load are not known with any degree of certainty, and to expect a mains engineer or meter-fixer to know which way the phases were rotating is rather outside ordinary working conditions. Messrs. Ratcliff & Moore.

Professor Robertson's remarks generally confirm our own experience. With regard to "Aron" clock meters, we recently had

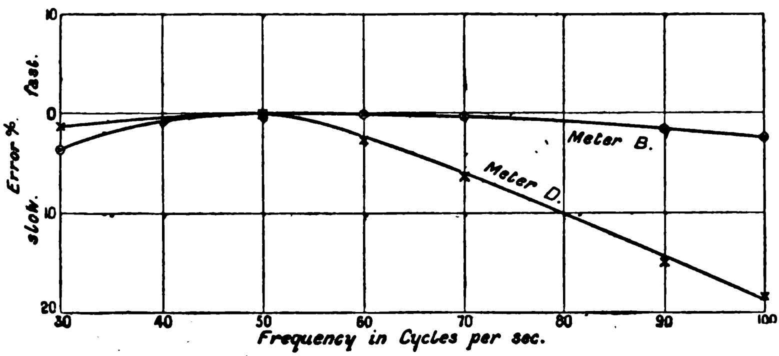


FIG. M.

a very interesting case in which a meter registered very slow on one particular load, the calibration curve dipping down to the extent of 7 or 8 per cent. The abnormal error appears to have been due to resonance between the pendulums, which apparently had the same period of vibration at that particular load. As a rule, this effect is always avoided by the difference in the train-gearing of the two clocks.

We have not yet been able to verify experimentally Mr. Irwin's theory of the effect of wave-form, but if the frequency test is sufficient to discriminate between those meters which are affected by changes in wave-form and those which are not affected, it will be an extremely useful and simple test, and one which would not be difficult in application. We have tested meters B and D with frequencies from 30 to 100 periods, and the results given in Fig. M appear to bear out Mr. Irwin's theory. We quite agree that meters A and B can be considered independent of wave-form for practical service conditions. The method of recording the composition of the waves was not intended to represent an analysis; but as we had not time to make

Messrs. Ratcliff & Moore.

any analyses, it serves the purpose of a record from which we can at any future time reproduce the waves.

We are pleased to note that Mr. North agrees with us as to the greater importance of accuracy than trifling shunt losses, and also as regards the losses incidental to the use of ampere-hour meters. We fail, however, to see that the makers can blame the users of meters for the cramped design, etc., and consider that it is for them to convince the users of the advantages of good meters. We have not had much experience with dynamometer type motor-meters on alternating currents, but refer in the paper to the precautions necessary to be taken when they are used. Successful results have been obtained with "Aron" meters on alternating-current circuits. Induction or clock-type meters are to be preferred for working off current transformers. The advantages of induction meters are admitted, but if it should be found that they are affected by wave-form, the dynamometer type is recommended as an alternative. We do not consider that the interaction effect is quite such a simple one as his formula would suggest, and it would appear from further experiments that it depends to a great extent on the strength and phase of the main currents in the two elements of the meter, and is not therefore merely due to an interchange of volt flux as Mr. North suggests.

Mr. Trent complains of the position in which switchboard designers arrange for meters, etc., to be fixed; but he appears to overlook the fact that the makers invariably claim that their meters are suitable for use in such positions. He appears to confirm our statement that there is room for improvement in ball-bearings.

Mr. Jepson refers to the disintegration of the mercury in meters, and states that it is really a breaking-up of the mercury into microscopical globules. There appears to be strong support for this explanation. The higher voltage drop in the damped type of commutator ampere-hour meter is proved by actual tests, and is no doubt due to the fact that more energy is spent in the armature when damped than when undamped. The jewels in large watt-hour meters of the dynamometer type are usually mounted on springs. With regard to the testing of "Aron" meters, Mr. Jepson rather begs a point when he states that it is only necessary to test at one load. Experience has shown us that the curves of "Aron" meters are not always straight lines, and it is only by making tests on several loads that faulty meters are discovered. Cleaning of the commutators, which he recommends, is obviously not practicable when the meters are fixed on circuit. As regards the pitting of the pendulum arbor pivots, we have not had the later type of meters in use for a sufficient length of time for this trouble to develop, so cannot say whether it has been cured or not. With regard to the testing temperature, 60° F. is a usually recognised temperature, and is probably a fairly average one. It has been fixed as a standard by the British Engineering Standards Committee. Testing meters at a low temperature, such as 50° F. for instance, would not be practicable unless undertaken in a specially

Messrs. Ratcliff & Moore.

designed test-room, with a staff specially equipped for working under these rigorous conditions. It is usual when meters are required to work under special conditions to specify the temperature at which they are to be calibrated.

Mr. Grant's experience with electrolytic meters confirms our own. It is not unusual for the mercury to be shot out of the motor meters as a result of severe short circuits.

In reply to Mr. Cramp, we have had no experience with reversible meters for ordinary service work. Direct-current motor meters are not, as a rule, accurate when reversed, and alternating-current motor meters would also be inaccurate under these conditions if compensated for friction in one direction only. "Aron" meters should be entirely satisfactory for this class of work. Excellent results have been obtained with reversible battery meters of this type.

Proceedings of the Five Hundred and Twentieth Ordinary General Meeting of the Institution of Electrical Engineers, held on Thursday, April 6, 1911—Mr. S. Z. DE FERRANTI, President, in the chair.

The minutes of the Ordinary General Meeting, held on March 23, 1911, were taken as read, and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Hall.

The following list of transfers was announced as having been approved by the Council :—

TRANSFERS.

From the class of Foreign Members to that of Members—

Professor R. Arno.
Osuke Asano.
Daizaburo Awoki.
Toraji Bannai.
Joseph Banneux.
Dr. Joãs N. Baptista.
Oscar Bihet.
Arthur von Boschan.
C. E. L. Brown.
Knud Bryn.
Roderick B. Bumiller.
Marius Cailho.
Baron de Capanema.
Professor H. S. Carhart.
Jules Carpentier.
A. E. R. Collette.
Professor C. L. Cory.
Professor F. B. Crocker.
Joseph P. Davis.
Felix Deutsch.
Fred. M. N. Dresing.
Thos. A. Edison.
Professor J. Epstein.
John Fargues.
D. Farman.
Ichisuke Fujioka.
Professor Eric Gérard.
Louis Goichot.
Xavier Gosselin.
T. Guilleaume.
E. J. Hall, jun.
George A. Hamilton.
John Hammar.
T. Hasegawa.
S. Hayashi.
Andre Hillairet.
Colonel Huber.
H. Igarashi.
Samuel Insull.
Takeo Iwata.
Christian Jensen.
J. L. W. V. Jensen.

TRANSFERS—*continued.*

Arthur Jourdan.
Hayazuchi Kodama.
Otto Peder Krogh.
Kosaku Kumakura.
R. McAlister Lloyd.
T. D. Lockwood.
Jacques Manne.
Julius Martin.
T. Commerford Martin.
Felix J. L. Mélotte.
Henri Menier.
E. Mercadier.
Edgar W. Mix.
Junsuke Miyakè.
D. Monnier.
Kotaro Morishima.
Iwasaburo Nakahara.
Hatsune Nakano.
Samuel G. Neiler.
F. C. C. Nielsen.
S. D. Niwa.
Paul Nolet.
T. Norberg-Schulz.
Saitoro Oi.
Masayuki Otagawa.
L. de la Peña y Braña.
Albert Petersen.
E. B. Petersen.
R. V. Picou.
Richard Henry Pierce.
Einar Rasmussen.
Edouard Rau.
H. Renisch.
Edwin Wilbur Rice, jun.
G. Paul Roux.
W. D. Sargent.
W. J. Schónau.
Gustave P. Seligmann-Lui.
H. Serrin.
Arnold von Siemens.
Wilhelm von Siemens.
Dr. R. Sissingh.
Carlos Paz Soldan.
F. J. Sprague.
W. Stanley, jun.
Commodore Edw. Suenson.
Bentara Tamaki.
Nikola Tesla.
Julius Timm.
Fred. W. Tischendoerfer.
Professor Dr. A. Tobler.
G. de la Touanne.
Lawrence B. Trant.
Makoto Tsuboi.
Carl Albert Unbehaun.
Charles Walckenaer.
Masahide Yoshida.
C. Zipernowsky.

From the class of Associate Members to that of Members—

Hugh Bourne.
Andrew Stewart.

From the class of Associates to that of Members—

Philip Ibotson Unwin.

From the class of Students to that of Associate Members—

Lewis Winter Barney.
Alexander Beggs Burgess.
William Francis Furse.
Hermon Amos Kelsall.
Wyndham D'Arcy Madden.
Thos. Jacob Sack.
Henry William Taylor.
Wesley Turner.
Joseph H. Wilkinson.
Geoffrey H. Wilson.

Donations to the *Library* were announced as having been received since the last meeting from Dr. L. A. Bauer, Professor A. Battelli, Dr. E. Haanel, C. W. Hill, Professor T. Mather, The Municipal School

of Technology, Manchester, Messrs. C. A. Parsons & Co., Professor D. Robertson, Schweizerischer Elektrotechnischer Verein ; and to the *Museum* from the Municipal School of Technology, Manchester, Major W. A. J. O'Meara, and A. E. Porte, to whom the thanks of the meeting were duly accorded.

The following paper, "Wireless Telegraph Working in Relation to Interferences and Perturbations," by J. E. Taylor, Associate Member (page 119), was read and discussed.

WIRELESS TELEGRAPHY IN RELATION TO INTERFERENCES AND PERTURBATIONS.

By J. E. TAYLOR, Associate Member.

(*Paper received February* 8, 1911. *Read before* THE INSTITUTION *April* 6, 1911, *and before the* NEWCASTLE LOCAL SECTION *March* 27, 1911.)

The working efficiency of a radio-telegraph installation is very greatly influenced by its freedom or otherwise from interferences and perturbations of all kinds. Considerations of immunity from avoidable disturbances have, therefore, a very important aspect in the matter of selection of suitable sites and in the general design and lay-out of stations, especially those intended for coast station traffic with ships at sea. The situation of a radio-telegraphic coast station should be chosen primarily with the object of commanding traffic from ships over as wide an area of sea as possible consistent with despatch and economy in disposing of the traffic handled. The character of the receiving apparatus used also demands consideration in the choice of site, since receivers of the auditive type have now, because of their undoubted superiority for the purposes of coast station work, almost entirely replaced those of the recording type. The effective ranges, for transmitting and receiving respectively, are factors of primary importance. The former can be to a large extent regulated by the use of suitable power, but the latter turns largely upon the transmitting power of the ship installations. It therefore becomes necessary to conserve the receiving efficiency of the coast station apparatus to the largest possible extent. The receiving range of a station using auditive receivers is practically limited only by the inability of the operator to interpret signals of less than a certain strength in the telephone receiver. In these circumstances it will be readily perceived that almost absolute silence in the building in which the apparatus is housed is very necessary. The extent to which this is desirable can only be fully appreciated by those who have gauged for themselves the dulling effect of slight external sounds when listening intently to radio-telegraph signals even of moderate strength. This constitutes a strong reason for a special and separate building in a quiet locality for radio-telegraph coast station work, rather than appropriating portions of existing buildings such as post offices for the purpose. The considerations guiding selection of premises for telephone exchange purposes have little in common with those determining suitability for radio-telegraph business. The order of immunity from

disturbance desirable in the latter case is entirely different from the former. Road and railway traffic and the sounds inseparable from populous localities must be strictly avoided unless heavy expense is to be incurred in the type of building and sound proof contrivances necessary to reduce sufficiently these obvious sources of disturbance. There are, of course, a number of other factors concerned in the rather wide subject of selection of sites and design of buildings: notably facilities for obtaining electrical power supply rather than running small and troublesome self-contained power plants involving costly running charges; suitable living accommodation for operators; avoidance of maintenance of long land circuits for connection with the main telegraph system, etc., etc., but these considerations hardly fall within the scope of this paper. Sites which are too much exposed to the force of the elements in bad weather are likewise to be avoided as far as possible.

Interferences and perturbations in radio-telegraph working may be broadly divided under five main heads :—

1. Direct interference by extraneous sounds and noises.
2. Electrical interference by local inductive influences.
3. Electrical interference by waves from other stations.
4. Atmospheric electrical perturbations.
5. Perturbances of wave-propagation efficiency of the dielectric medium.

The direct interference, under the first head, is, of course, avoidable and need not be further dwelt upon.

Local Inductive Disturbances.

The interference by local inductive disturbance referred to under (2) above is also avoidable, but special arrangements are necessary which demand some attention. In the first place, seeing that a land circuit connection is an essential feature of a coast station and that it will generally be desirable to terminate the circuit in a position near the radio-telegraph apparatus where it can readily be attended to by the wireless operator, it is necessary to take precautions to ensure that there is no electrical disturbance of the radio-telegraph receiver by the operation of the land circuits. Such disturbance may, in the case of Morse apparatus on the land circuit, arise from sparking at relay and key contacts, electrostatic or electro-magnetic induction from circuit leads, or from battery leakage direct or *viâ* the earthing elements. There may also be direct induction from the external line to the aerial wires of the radio-telegraph plant, due either by the operation of the land circuit itself or to inductive disturbance re-transmitted from other circuits on the line of route joined by the land circuit at some distant place. In the case of a telephone connection to the station, the latter will be the principal source of trouble to be

guarded against, though the calling apparatus may also produce disturbance similar to that of the Morse telegraph. To obviate these troubles, the following precautions are adopted :—

(*a*) Telegraph or telephone circuits are led into the station by a short length of underground cable, so that the exposed land line is at least 30 or 40 yards distant from any part of the aerial wire system of the radio-telegraph plant.

(*b*) The land line apparatus and wiring are located in the operating room as remote from the radio-telegraph apparatus as possible consistent with convenience in having both sets of apparatus manipulated by one officer.

(*c*) Twin wiring is adopted for the connections of the apparatus and batteries (if any). Lead-sheathed connecting wire may be used, but it will generally suffice to adhere to ordinary twin wiring, provided that care is taken to twine together the outgoing and return wires of both local and line circuits, so that there is no undue separation of the wires which form a circuit traversed by a given current. In other words, the wiring methods used in telephone exchanges to avoid induction are followed in radio-telegraph stations as far as possible.

(*d*) The necessity for having the land circuit apparatus under the surveillance of the wireless operator renders it desirable to provide a visual and noiseless call in the shape of a small telephone exchange glow lamp, which can be switched on by the operator in place of the sounder or other apparatus used on the land line. This glow lamp may, of course, be fixed in any convenient position to attract the attention of the operator wherever he may be engaged in the operating-room.

(*e*) The land-circuit earth connection should be made separately to an earth-plate distinct, and separated by at least a few yards, from the main high-frequency earthing system of the wireless telegraph plant. If the earth-plate is buried at a moderate depth below the surface of the ground immunity from interference on this score will usually be assured. An alternative plan is to " double back " the land telegraph wire and find earth at a convenient distant point.

(*f*) Interference from sparking at relay and key contact points will not usually occur if the scheme of twin wiring has been effectively carried out. If, in spite of these precautions, interference is still appreciable, it may be minimised by shunting the contacts by a condenser of about a microfarad capacity with a non-inductive resistance coil of about 500 ohms in series with the latter.

In addition to inductive disturbance of the wireless telegraph receiver by the land line there is also the reverse action to consider, viz., the powerful electrostatic induction of the wireless transmitting plant on the land line and Morse apparatus. If not guarded against, this induction may render itself evident in several ways. It may produce sparking in the coil windings of the Morse or telephone apparatus which will ultimately cause disconnections or contact faults. It may produce sparking at lightning protectors on the line, causing disin-

tegration of the carbon plates and frequent "earth" faults on the line. It may also, in conjunction with the inductive sparking, render the wireless telegraph transmission extremely audible on the land circuit telephone wire or, by secondary and tertiary induction, convey the signals with disagreeable intensity to trunk or other telephone lines on the route traversed by the land circuit. In the case of wireless telegraph transmitters with coupled or closed circuit excitation, troubles of this kind are not very apt to occur; doubtless because of the building up of the aerial oscillations by resonance and their extremely transient duration. In point of fact, it has been found that it is difficult to render induction from coupled wireless transmitters evident on telephone circuits unless inductive sparking is occurring at some point (such as the lightning protector) on the circuit at the same time. If such sparking be allowed to occur the signals are at once apparent. On the other hand, if "plain aerial" transmission, or any form of transmission involving pre-charging of the aerial system prior to disruptive discharge across the spark-gap, be used, strong inductive disturbances are liable to be created on neighbouring circuits. In this case the aerial oscillations are not built up by resonance but commence with maximum amplitude of vibration, while at the same time the aerial system is called upon to hold a high-tension charge for an appreciable interval before disruption occurs. This allows sufficient time for induced charges to accumulate in any neighbouring wires prior to the discharge of the aerial system through the spark-gap. On occurrence of the disruption at the spark-gap the induced charges are suddenly liberated on the neighbouring wires, hence the strong inductive effects produced.

So far as inductive disturbances due to coupled wireless transmitters are concerned, the precautions observed above in regard to elimination of induction on the wireless receiver are equally effective in neutralising induction on the land circuit. Methods of transmission involving precharged aerials are banned in the British Postal Telegraph Service except as purely temporary expedients, by reason of their emission of waves of a character very prone to produce interference with other wireless stations. This is referred to later.

The reaction of the high-frequency oscillations generated by the transmitter on the low-frequency transmitting plant such as high-tension transformers, motor-generators, etc., together with the means of protection adopted in the shape of high-frequency air-core choking coils and shunting condensers are well known, and call for no special comment. It may, however, be well to remark that in postal telegraph practice the wiring of the low-frequency apparatus is effected throughout with lead-screened cable. This is found effective in preventing sparking due to electrostatic induction whilst further aiding in reducing the effects of "back surges."

Disturbances arising from the motor-generator or other electrical machinery used in power transformation are liable to occur, either in the shape of vibration communicated acoustically or commutator

ripples producing trouble by electromagnetic action. Complete isolation of the running machinery from the operating-room, preferably by locating it in a separate structure, is desirable to eliminate the vibration effects. Commutator ripples are specially prone to occur in a penetrating and obtrusive form where power plant is installed for charging accumulators and are greatly accentuated during the process of cell charging. If, for convenience, the charging circuit is led to the operating-room switchboard there is a tendency for the iron fittings and framework of the switchboard to take up the humming of the commutator and emit it acoustically into the room. Doctoring up of the commutator and the use of special commutator brushes may be feasible in such cases, but it is considered preferable to avoid the trouble by excluding the charging circuit completely from the operating-room. Where trouble is experienced from commutator humming or sparking during the ordinary running of the plant (apart from the charging of accumulators) it is desirable to adjust the brushes whilst listening on the telephone receiver.

Mutual Interference between Stations.

The consideration of mutual disturbance produced by radio-telegraph stations on one another opens up a peculiarly involved problem in view of the number of variable factors concerned. In the first place, the whole question of tuning and selectivity is involved. The theoretical investigation of the possibilities of selective signalling from contiguous stations by the use of wave-lengths differing sufficiently from one another presents no insurmountable difficulties, but its practical realisation is quite another matter. It is comparatively simple to plot out the resonance curve of a transmitter, and work out the varying degrees of dissonance necessary to ensure immunity from disturbance on a given type of receiver at various distances away, assuming constancy of radiated waves both in respect of strength and wave-length. This has frequently been done, but it is of very little utility in practice even when the stations concerned are working over fixed ranges with fixed wave-lengths. It is too frequently overlooked that the resonance curve obtained is really a mean of a number of curves of greater and less amplitude. In other words, the variability of the amplitude of vibration at the transmitter must be allowed for in practice. In addition a substantial margin of amplitude must often be provided at the transmitter, to compensate for the variations of the distant receiver, quite apart from the question of providing an ample working margin on the communication. Further, this margin is itself highly variable in practice by reason of the necessity for increasing power at times of atmospheric electrical disturbance up to the limits of the plants at disposal. In certain tracts of sea around the British Islands where congested radio-telegraph conditions arise it is also unfortunately sometimes necessary, under present working arrangements, to rely largely on "shouting down" interfering stations. The interfering

stations concerned may be ships of various nationalities or Continental coast stations. It is, however, due to coast stations generally to remark that amicable working is maintained on a "give-and-take" policy, in spite of the trying conditions under which the communications are often effected. Although, under the International Radiotelegraph Convention, the range of wave-lengths allotted for ship to shore working is strictly limited and defined, it is fairly certain that no radical improvement in working conditions can at present be expected from any system of allotting distinctive wave-lengths for individual coast stations. The increased selectivity theoretically obtainable would not, in practice, assist matters to any great extent, especially in view of the limited range of wave-lengths adaptable to the purpose, even if standardisation of apparatus and wave-lengths were carried to a much greater state of perfection than holds at present; whilst the additional complications introduced in the apparatus, either of the ships or the shore stations, would be distinctly objectionable. Many of the manipulative difficulties at present experienced in radio-telegraph working would, however, be largely reduced if less disturbing and more speedy types of transmitters were adopted at certain Continental stations. Much benefit would likewise accrue from the adoption of a standard method of easily and readily regulating the strength of antenna current to suit the particular communication on hand, such as by a regulating coupling between the closed circuit and the aerial circuit in coupled transmitters. This is much simpler and better than any method which involves regulating the power applied to the transmitting plant, mainly for the reason that readjustment of power involves other readjustments in the transmitting plant, particularly at the discharge-gap of the closed circuit. Such readjustments are not only cumbrous and slow, but usually entail a certain element of risk to the operators, as dangerous shocks may be obtained from the high-tension side of the plant. A further advantage of such a method of regulation as that proposed, beyond its obvious celerity and simplicity, is that as the coupling is reduced, the waves radiated have, for equal amplitude, far less disturbing or interfering qualities than those emitted by more strongly coupled transmitters.

The complex nature of the mutual interference problem, involving, as it does in practice, interference between stations for naval, coast, ship, fixed communication and experimental purposes, may be further realised by a consideration of some of the principal factors in what may be termed the "mutual disturbance coefficient." In the numerator of such a coefficient would appear quantities representing maximum antenna current, radiation coefficient, wave-form damping factors (both of transmitter and receiver), absorption coefficient of receiver and constant representing protraction in signalling. In the denominator, distance and dissonance would be mainly concerned. Further constants involving certain characteristics of the transmitter, such as sparking frequency, and other characteristics of the receiving

appliances, such as the degree of sensibility to particular wave-train periodicities, should also figure in the expression.

It will thus be seen that the problem of selectivity in radio-telegraph working involves much more than mere tuning. The degree of dissonance, important though it is, is only one factor out of many. In giving more detailed consideration to the subject, it will, perhaps, be well to subdivide the interference-producing elements into a number of heads or types, as under :—

(*a*) Electrostatic interference.
(*b*) Pre-charged aerial, or "plain aerial" interference.
(*c*) Interference by heavily coupled transmitters.
(*d*) Interference by lightly coupled transmitters.
(*e*) Interference between continuous wave and spark systems.
(*f*) Interference by emission of accidental waves.
(*g*) Damping in transmitters and receivers in relation to interference.

(*a*) *Electrostatic Interference.*—Stations in sufficiently close contiguity are liable to powerful electrostatic induction across from aerial to aerial tending to produce forced oscillations, the effect of which on the receiver it is extremely difficult to annul. This is an effect which decreases very rapidly with increase of distance of separation. The range over which a station exerts this influence depends in the first place on the character of the transmitter. It is generally more pronounced in transmitters of the open-circuit type, in which the aerial system is charged up to a high potential prior to discharge across the spark-gap. These may be conveniently designated "pre-charged aerial" methods in contradistinction to coupled transmitters. In the latter, the electrostatic field generated about the aerial is strictly limited in extent. No time is given for expansion beyond the distance of, at most, a quarter wave-length from the transmitter. Further, the aerial oscillations are built up by resonance and only attain their maximum amplitude after a number of swings, whereas pre-charged aerial methods involve maximum amplitude of aerial oscillations at the commencement of discharge and are therefore much more "forcing" in character, especially as the first swing or two cannot be strictly of the same periodicity as those following subsequently, owing to the fact that the effective capacity of the aerial is at its maximum prior to discharge. That is to say, every part of the aerial is then charged to the full potential, whereas when the oscillations are fully established, the aerial has a potential gradient from zero at the centre of the oscillating system to a maximum at the upper extremity of the aerial conductor. The main feature differentiating the two methods so far as electrostatic interference producing qualities are concerned, however, is that the pre-charged aerial method produces an extensive and obtrusive electrostatic field, whilst the electrostatic field produced by the coupled transmitter is negligible in comparison, and can be made wholly unobtrusive in its interference producing qualities. In this

connection one well-known system in which the pre-charged aerial method is usually adopted, viz., the Lodge-Muirhead, will at once be brought to mind. Excellent as are the results which have been obtained with this system, both from the point of view of range of communication and syntonisation of stations when using the special devices adopted or invented by the promoters, practice has shown that it is not advisable to attempt to work a Lodge-Muirhead and a Marconi type coupled circuit station using earth in too close proximity or the result will be disastrous for the latter. Though the matter has not yet been put to the test, the following suggestion regarding the *modus operandi* of the Lodge-Muirhead transmitter is offered for what it may be worth. By the character of the results obtained * together with the remarkably quiet discharge and the lengthy trains of oscillations generated, the transmitter appears to operate rather as a high-frequency "singing arc" than a spark discharge. If so, the oscillations are maintained not by the inherent vibratory qualities of the radiator, but by a flow of energy from the transformer continued during an appreciable part of each half-cycle of the primary alternating-current supply. In this way the system would possess to a large extent the qualities of continuous wave methods rather than spark methods.

Referring again to electrostatic interference by precharged aerials, emphasis must be placed on the disability of the station experiencing interference at close quarters to "tune out" to the necessary extent by dissonance, assuming coupling methods and receiving appliances of the kind required for the efficient operation of a spark system. The obvious reason for this is that electrostatic induction from a pre-charged aerial determines an induced charge held on the aerial of the neighbouring station until the discharge occurs at the transmitter spark-gap. The induced charge is then suddenly released, with the result that oscillations are set up in the aerial and through the receiving system with a periodicity determined solely by the electrical constants of the whole receiving system, viz., the periodicity to which the receiver happens to be tuned. Obviously dissonance between the two stations will not affect this source of interference, and it will only be possible to reduce the trouble by greatly reduced coupling of the receiver or other special appliances.

(*b*) *Plain Aerial Interference.*—Interference by pre-charged aerials on distant stations is also of a very pronounced character; so much so that it is frequently possible to recognise the working of such a transmittter among signals from other stations that may be heard at the same time, by reason of the extended range of tuning adjustment over which the signals of the former are perceptible. This effect cannot, of course, be due to electrostatic induction, but is doubtless determined by the character of the waves emitted. In the first place, it is highly probable that there is a pronounced impurity of wave-form throughout the train, due to damping in the emitter, irregularities in the spark

* *Proceedings of the Royal Society*, vol. 82, p. 227, 1909.

discharge, and forcing action of the transformer, or other source of high-tension current. In other words, the oscillating system may be too heavily coupled to the driving E.M.F. At the commencement of each wave-train, when the amplitude is greatest, this impurity will be accentuated by the variation in "effective capacity" of the aerial already referred to, and also probably by the fact that the electrical conditions in the dielectric of the spark-gap do not assume their normal state instantly, but take an appreciable time to settle down to something approaching constancy. At any rate, whatever the reason may be, there is no gainsaying the objectionable nature of such methods of transmitting so far as the ordinary spark system receivers are concerned.

(*c*) *Interference by Heavily Coupled Transmitters.*—Heavily coupled plain spark transmitters give rise to interference both in respect of impurity of wave-train, due to forcing at the transmitter, and in respect of the well-known double wave emission. Very frequently, however, the former so overshadows the latter that no distinct trace of separate waves is perceptible at the receiver. The whole resonance curve becomes a blunt hump with an extensive range of interference on the scale of tuning adjustments at the receiver. In this category, it is feared, many of the continuous wave and even the quenched spark transmitters must be placed, unless they be connected in such a way as to reduce damping in the aerial system to a sufficiently small amount. This can, of course, only be achieved by sufficiently reducing the radiation coefficient of the aerial.

(*d*) *Interference by Lightly Coupled Transmitters.*—The Marconi type lightly coupled spark transmitters have most certainly proved themselves to occupy a premier position as regards elimination of objectionable interference. With a sufficiently light coupling great purity of wave-form is attainable and a high degree of selectiveness assured. Decrease of range of communication governs the degree to which reduction of transmitter coupling can be carried, but for communication between fixed stations on a fixed wave-length this can be compensated to a large extent by sharply tunable receiving appliances for picking up the waves. For ship and shore communication a very light coupling is impracticable, both by reason of the diminution of range and because if sharp tuning is necessary there will be difficulty in getting into touch. Calls would be lost, and the communication would lose its utility. For this class of work, therefore, it is necessary to have a moderate bluntness of tuning, both on transmitters and receivers. There is, however, no good reason why all installations for coast and ship communication work should not be provided with "stand-by" and "tune" adjustments, not only for the receivers, but for the transmitters. If such a scheme were universally adopted, the "stand-by" sides of the apparatus being used only for calling and look-out purposes and the "tune" sides for actual transmission and reception of messages, a very great improvement might be looked for in the conditions of working to ships at sea so far as the British and Continental seaboards are concerned. It must be admitted

that under present conditions of operating coast station services, there are periods during which the "jamming" of the signals of one station by others is so pronounced that confusion begets confusion and "shouting down" becomes the order of the day.

Even in coupled transmitters it will occasionally happen that the transmitted waves will be of a more obtrusive and interfering character than the degree of coupling would indicate. This is probably due to forcing and prolongation of the trains of oscillations in the closed exciting circuit, semi-continuous trains of oscillations being produced by an overplus of available energy from the transformer. When this is the case, the oscillations are of impure wave-form and give rise to impure wave emissions from the aerial system. Effects of this kind are much more pronounced where the capacity of the condenser in the closed circuit is relatively small and a large type of high-tension transformer is used. Unfortunately this scheme of transmitting plant appears to have been rather largely adopted in Continental installations.

(*e*) *Interference from Continuous Wave Systems.*—With so-called "undamped" wave systems it becomes necessary, by reason of the small amplitude of vibration excited in the transmitting aerial, to rely to a much greater extent on the cumulative properties of the tuned receiver. It then becomes very necessary to provide closed receiving circuits of extremely small damping in order that the decreased amplitude of vibration may be compensated by making use of a much longer consecutive series of waves in the receiver. At first sight it might be supposed that a very high degree of immunity from disturbance would be secured as between such a system and a neighbouring spark system with a small degree of dissonance in wave-length. Though full tests have not yet been made on this point in the Post Office service, yet there is good reason for suspecting that the degree of immunity from mutual interference between spark and arc systems is not of a high order where the stations are not greatly separated from one another. This is not altogether surprising in view of the "forcing" action which governs the operation of the "undamped" wave transmitter, so-called. The term "undamped" is surely a misnomer as any one oscillation considered separately must be very appreciably damped and the damping necessarily tells on the purity of wave-form. "Continuous wave transmitter" is a better term in this respect, in spite of the fact that absolute continuity is not necessarily obtained.

(*f*) *Interference from Accidental Waves.*—Interference produced by emission of accidental waves may sometimes occur if conductors in the neighbourhood of the aerial wire, such as the insulated sections of the stay wires or ropes to the mast, are allowed to spark to ground or to one another. This may happen by reason of the powerful electrostatic induction set up. When it occurs, the discharging conductors emit waves of a period determined by their own electrical constants.

(*g*) *Damping in Relation to Interference.*—The effect of damping *per se* so far as transmitters are concerned is doubtless bound up with the

influence produced on the purity of wave-form and consequently on the interfering qualities of the transmitter. A more potent factor accruing from damping, however, may be the deformation of waves due to increased "driving" or "pumping" of energy into the oscillator to maintain the oscillations. So far as the receiver is concerned, experience shows that a moderately damped receiver is not nearly so selective in its action as a very slightly damped one.

Regulation of interference at the receiver is, of course, a very important proposition and one to which various investigators have given very close attention. It is indeed unfortunate that complete elimination of disturbance by regulation of the receiving appliances is not feasible, as in that case the difficulties experienced in successfully legislating for the regulation of transmitters would not arise. Without making any attempt to enumerate or describe all the various devices of a more or less successful kind which have been tested or proposed for

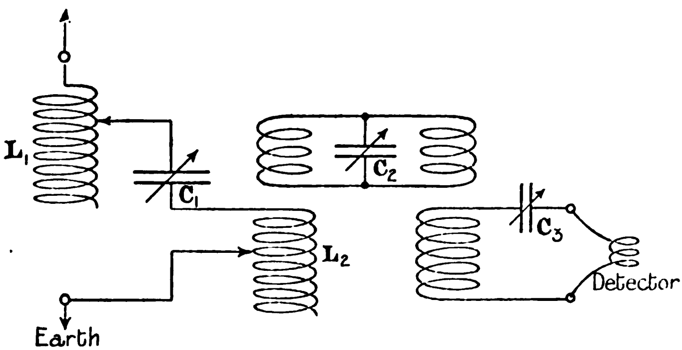


FIG. 1.—Scheme of Marconi Multiple Tuner.

the production or prevention of interference at the receiver, an examination of the well-known Marconi "multiple tuner" may perhaps be useful. The connections in simplified diagram form are shown in Fig. 1.

This instrument is apparently an attempt to combine in one, what are, at first sight, two principles or methods of reducing interference. Primarily, the object is to make use of variable coupling while providing an intermediate circuit of very small damping. The end achieved by the use of the intermediate circuit, so far as interference reduction is concerned, is to enable the maximum benefit to be derived from the reduction of coupling. Without its use, since both the detector and aerial circuits possess considerable damping coefficients, it would not be feasible to reduce the coupling to so great an extent and still preserve signals of readable strength. In the Fig., L_1 is the variable aerial inductance wound with a type and gauge of wire found most effective experimentally: C_1 is the variable aerial condenser with thin high-quality ebonite dielectric; L_2 is a supplementary inductance coil in series, induc-

tively coupled to No. 1 inductance spiral of the intermediate tuning circuit; C_2 is the intermediate circuit tuning condenser similar in type and construction to C_1; whilst C_3 is the variable condenser for tuning the detector circuits. Both windings of the intermediate tuning circuit are mounted on a common spindle so as to be capable of rotation through an angle of 90°, serving to vary their couplings with the respective fixed windings simultaneously from a maximum down to zero. The values of the windings, type, and gauge and insulated wire, sizes of spirals and ranges of condensers adopted in the construction, have been determined by careful experiment with a view to producing the most effective results over the range of wave-lengths to which the tuner is adjustable. It is, of course, specially designed to suit the standard Marconi magnetic detector. The instrument is fitted with a switch for cutting in or out the intermediate tuning circuit and coupling adjustment. When the tuning circuit is cut out the inductance spiral L_2 is replaced by the detector winding, the connections being transferred from the detector circuit by the operation of the switch. In this way one position of the switch places the detector coils directly in the aerial circuit in series with the adjustable inductance and condenser, whilst the other position brings the special tuning circuit and coupling adjustment into operation. The two positions of the switch are known as the "stand-by" and "tune" positions. Rough tuning only is afforded on the "stand-by" side so that the detector is sufficiently responsive over a large range of wave-lengths to transmitters of ordinary adjustment. On the "tune" side a sufficiently reduced coupling determines sharp tuning and a high degree of selectivity so that disturbing waves of slightly different length can be eliminated or sufficiently reduced unless of much greater strength than those to which the instrument is adjusted. The special form taken by the intermediate tuning circuit is apparently the result of an attempt to introduce a second principle of interference reduction, otherwise it is not obvious why the condenser is not placed in series with the two windings. As arranged, there are two separate resonant circuits of identical type and oscillation period, the condenser C_2 being common to both. There is therefore a coupling between these two circuits of a strength determined by the smallness of the capacity of the condenser. It is assumed that this disposition of the circuits has been adopted to bring about an enhanced selectivity after the fashion conveyed in Fig. 2. A genesis of the scheme of connections is there shown. At A is a simple intermediate circuit with condenser in series. At B the intermediate circuit is doubled, two additional condensers being added for the sake of symmetry. If the halves of the circuit are each adjusted so that on removing the other they would still remain in tune with a particular wave, it is evident that the circuit as a whole (assuming the connection from *a* to *b* removed) will be vibrating in its first harmonic with potential nodes at *a* and *b*. Under these circumstances a connection amounting to almost a short circuit may be placed across the circuit joining the points *a* and *b* without appre-

ciably disturbing its operation. Any oscillations communicated to the spiral L_1 would then be short-circuited through the connection a, b, and prevented from affecting the other part of the circuit unless they have the frequency of the first harmonic, in which case (assuming negligible dissipation or resistance losses in the condensers and inductance spirals) the latter would likewise present no impedance to the impressed oscillations and would therefore take them up and communicate them to the detector. Such a scheme of connections would, however, involve the simultaneous adjustment of at least two condensers in the intermediate circuit. By adopting the condenser itself as a shunt or short circuit as shown at C, it is made common to both circuits and greatly simplifies the adjustment. It is clear, how-

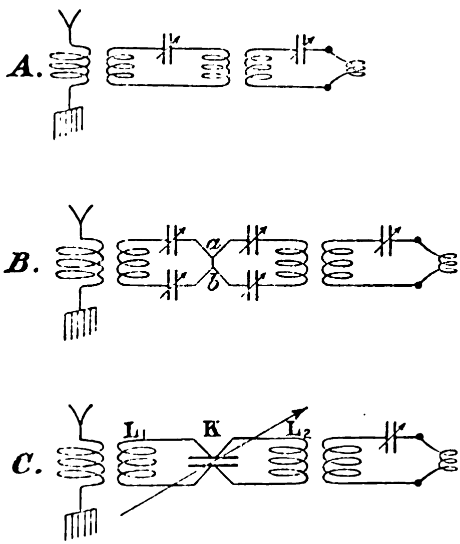


FIG. 2.—Genesis of Circuits of Marconi Tuner.

ever, that the shunting method is but a special adaptation of the reduced coupling plan; for an absolute connection across the intermediate circuit would, in the absence of mutual induction between the two halves, confine oscillations entirely to the first part of the circuit, whatever their periodicity.

In contrast with coupling methods of reducing interference, various plans of divided circuits have been proposed or used in which the impulses conveyed by one branch are annulled by those conveyed by the other, except to the extent necessary for the interpretation of the signals required. In these methods the required signals are "tuned in" as against tuning out undesirable impulses. Fessenden's "differential" method and S. G. Brown's "bridge" method are examples of

this class. The basis of the bridge scheme is shown in diagram in Fig. 3.

If the two branches of the divided circuit are absolutely symmetrical all received impulses will divide equally and no effect will be produced on the detector (which occupies a position corresponding to the galvanometer in a Wheatstone Bridge). A very slight disturbance of the balance by shifting the point of the earth-wire connection to right or left will determine signals on the detector from the branch best tuned to the received impulses. If these impulses consist of a sufficiently long train of waves discrimination is effected between these and any other impulses (even if of the same periodicity) if such other impulses are of a more rapidly damped

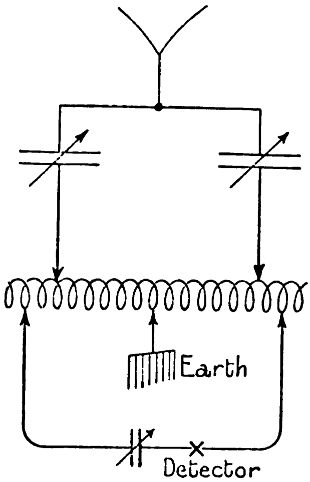


Fig. 3.—" Bridge " Scheme of Interference Preventer.

character. A "valve receiver" interference preventer based on a similar principle has been patented by Marconi.

It is not abundantly clear that devices of this kind possess advantages over, or involve any further principle than, that of reduced coupling. Greater promise of satisfactory elimination of disturbances and perturbations is afforded, in the writer's view, by the adoption of non-earthed directive aerials, at any rate, so far as the shorter waves in practical use are concerned. For communication over short distances between fixed stations, simple balanced directive aerials disposed to radiate in the line of communication give promise of very satisfactory results. These take the form of a vertical triangle, the apparatus being connected in circuit at the midway point of the base line, no earth connection being used. The properties of such aerials have been very fully investigated by Bellini and Tosi and confirmed by Post Office

investigations. Such a system is responsive only over a very limited range of wave-lengths determined mainly by the length of base line. This should be as large a fraction of the wave-length used as may be practicable. Post Office tests have shown that very powerful long-wave stations may be freely operated at comparatively short distances away without producing the least disturbance on such a system, quite irrespective of directional properties. Provided the directive system is, in itself, accurately balanced with regard to neighbouring conductors such as stay-wires to mast, etc., and is arranged with its mean plane of propagation at right angles to the line joining it to the disturbing station, powerful stations may be operated at close quarters without interference, irrespective of wave-length used. By making the best use of these properties and combining them with well-tuned transmitters and receivers quite a remarkable degree of immunity from disturbance by neighbouring stations or atmospheric electrical perturbation can be secured.

The use of transmitters of high sparking rates or intermittency producing a constant musical note in the receiver lend themselves to acoustical methods of reducing interference both by reason of the possibility of resonating acoustically to the spark frequency and by the comparative ease with which signals of high and constant periodicity can be magnified at the receiving station. This method appears to have been fully worked out by the Telefunken Company, but the plan has not yet been put to trial in the British Telegraph service.

Atmospheric Electrical Perturbations.

The phenomenon known in operating parlance as "X's," otherwise parasitic impulses or "atmospherics" present a wide variety of characteristics depending upon the latitude in which they are observed, the season of the year, and the time of day. They manifest themselves in the auditive wireless receiver as a series of scraping, scratching, or explosive noises of various intensities. Less frequently they render themselves evident by variable fizzing or frying noises in the receiver. They present distinct periodic characteristics in all latitudes, being stronger, more persistent, and prevalent during the summer than the winter months whilst they also present distinct periodic variation connected with the times of rising and setting of the sun, though varying very greatly in intensity and prevalence from day to day at all times of the year. During thundery weather, especially in the early stages of a storm, they manifest themselves with great intensity and are frequently precursors of stormy weather. This relation to the hours of daylight and darkness is analogous to that of the diurnal variations of terrestrial magnetism, whilst also the phenomenon is closely assimilated with certain forms of earth-current disturbances perceptible, owing to their rapidly varying character, on earthed telephone lines. At periods of magnetic storms no exceptional characteristics are noted unless it be that they are then less marked than usual. This appeared

to be the case during the exceptionally severe magnetic storm of September 25, 1909. This type of magnetic storm, however, is of a sluggish character, and, so far as the writer is aware, the variations which occurred were in no case sufficiently quick in their rate of change to produce any exceptional effects even on ordinary earthed telephone circuits. In these circumstances it could hardly be expected that high-frequency effects on wireless receivers would occur.

During thundery weather, atmospheric impulses are always very pronounced and occasionally cripple the working of the coast stations in this country for several hours together or even, in exceptional cases, for a whole day. Whenever they are of a persistent or continuous character they necessarily limit the working ranges of the stations to a degree depending on their intensity. They constitute a factor which should not be lost sight of in the design and scheme of construction of coast station plant, a margin of power being desirable to meet this exigency.

In the winter months, in this country, these disturbances are rarely strong enough to interfere seriously with traffic whilst they are sometimes totally absent for days together. At this period of the year the disturbances generally possess also characteristics of sharpness and individual isolation from one another which differentiate them to a large extent from those of the summer-time. Having regard to these winter characteristics the writer arranged for a series of observations to be taken simultaneously at all the coast stations in this country during the week commencing December 11, 1910. The main objects of these observations were to determine, as far as possible :—

(*a*) Whether all stations are equally affected or whether the situation of individual stations has any relation to the susceptibility.

(*b*) Whether periods of disturbance are general over the country or confined to local regions.

(*c*) Whether individual disturbances affecting more than one station simultaneously can be traced.

(*d*) To determine the form and manner best adapted for observing and recording the disturbances in any future observations.

The test conditions and method of recording laid down are shown in Appendix I.

By a happy accident during the week chosen for the observations atmospheric disturbances of a more than usually pronounced type for the winter months were experienced on two or three days. The results obtained show that these disturbances affected practically the whole of the British islands, though they did not, apparently, possess the same characteristics of intensity at all places simultaneously. Concurrently with the period of heavy disturbance, a gale of considerable force sprang up and wrecked the wireless mast at the Isle of Wight (Niton) coast station.

The difficulties to be negotiated in carrying out such observations in a manner rendering the records at all comparable will be readily appreciated, especially in view of the consideration that one condition

obtaining was to be that the traffic work of the stations must not be interfered with. The times of observation were laid down as from 6 p.m. to 6.15 p.m. and from 11.45 p.m. to midnight at each station, partly from traffic considerations, activity in wireless signalling being much greater during the daylight hours in most localities; partly with the object of comparing average intensity of disturbance in the early evening with that holding during the night hours; and partly with the idea of securing that the 6 o'clock and midnight observations be taken by the same operator, thereby reducing the irregularity due to personal judgment. Other factors to be taken into account in interpreting the results may be summarised as follows :—

(*a*) Difficulty of discriminating between individual and prolonged erratic impulses, together with the personal factor involved in judging strength of impulses.

(*b*) Interference by noises arising from wind and rain in exposed positions, especially in view of the unsubstantial nature of the structures at many of the coast stations.

(*c*) Variations in types and schemes of connection of receivers.

(*d*) Variations in height and character of aerial system.

(*e*) Difficulty in differentiating between atmospherics and accidental signals from other stations.

(*f*) Jamming by signals at other stations.

(*g*) Stoppage of observations while disposing of traffic.

In spite of all these sources of variability a fair degree of consistency is shown throughout in the results obtained, as will be seen from an examination of the table given in Appendix II.

From this table charts showing the relative aggregate disturbances observed during each period for all stations have been prepared. A certain number of these have been rejected in making comparisons, for reasons given, viz. :—

Lochboisdale.—Station closed down at 8 p.m. No midnight observations taken. Short-wave aerial used, and receiver therefore relatively insensitive.

Tobermory.—Ditto.

Skegness.—Station in use for special tests with long-wave aerial. No observations.

Hunstanton.—Special form of receiver with direct coupling used. Short-wave aerial.

Niton.—Mast wrecked.

Lizard.—Noises of gale, jamming by signalling, and handling of traffic during observation periods rendered observations practically futile.

Malin Head.—Small height of aerial.

The "aggregate" charts for the remaining stations, viz. :—

Caister,	Rosslare,
North Foreland,	Seaforth,
Bolt Head,	Crookhaven,

are reproduced in Fig. 4. These exhibit very fair consistency, and show that if the disturbances were not precisely of the same character at each place there is at least no variation of a definite or marked character. In every case the aggregate disturbances for the

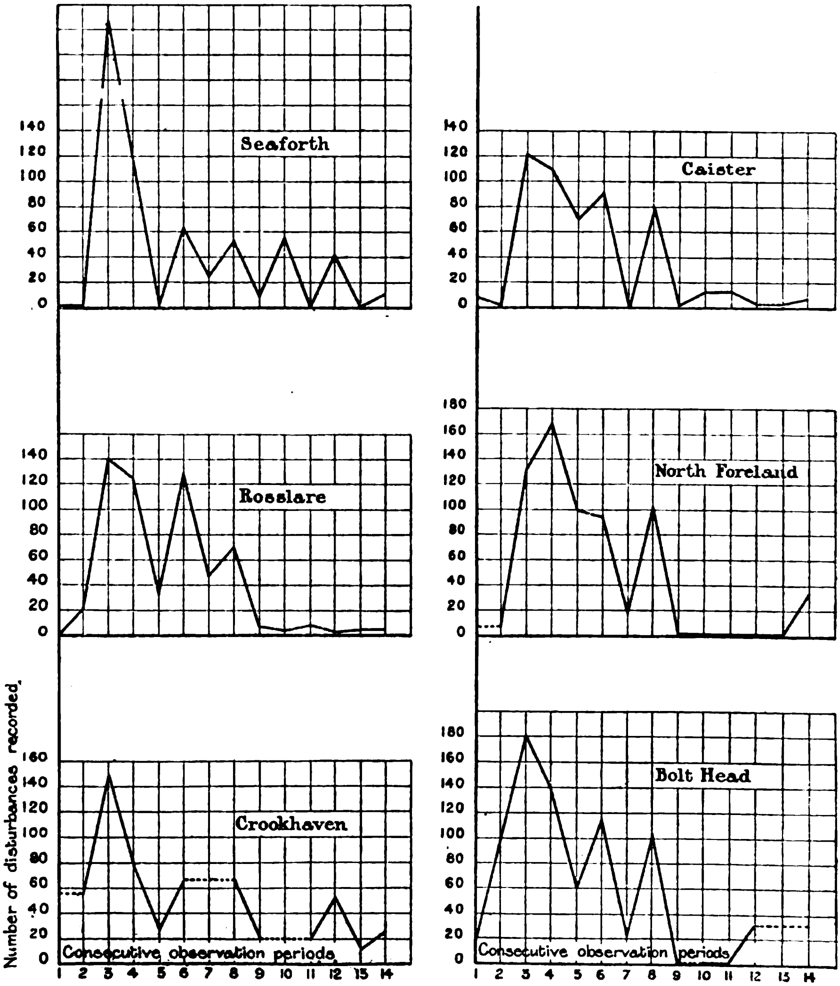


FIG. 4.—Charts of Aggregate Recorded Disturbances from Simultaneous Observations at Coast Stations, December 11–17, 1910.

third and fourth observations, corresponding respectively to 6 p.m. and 12 midnight, December 12th, are each greater than the aggregate for any other single observation at the same station. Also the greater disturbance experienced generally at midnight than at 6 p.m. is very

pronounced. But for the semi-continuous nature of the disturbances the maxima and minima periods would doubtless have been much more accentuated.

Though it cannot be stated absolutely that any single impulse was recorded at precisely the same time at a number of stations, there are indications, especially during the midnight observations of December 17th, that the stations from Hunstanton to Lizard and Rosslare were so affected. No special precautions were taken to ensure accuracy in timing the observations, but each station is supplied with a reliable

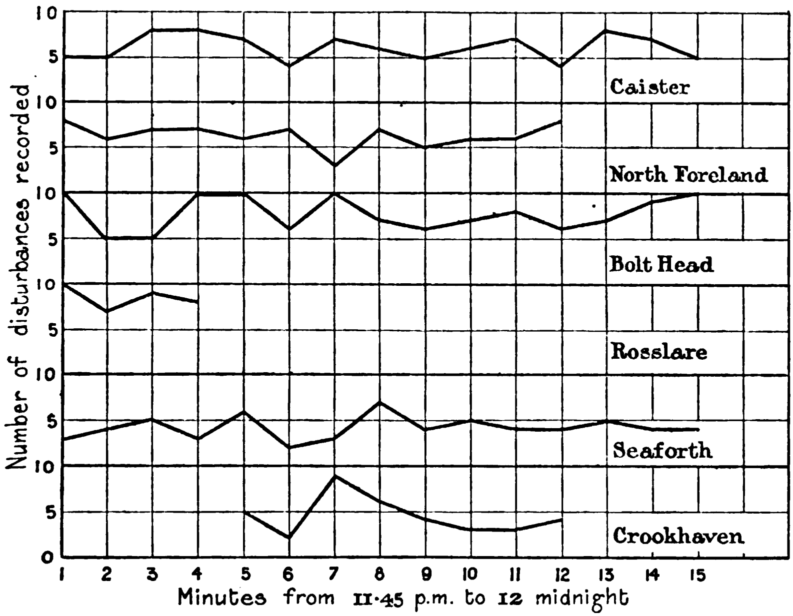


FIG. 5.—Character Charts of Atmospheric Disturbances at Various Coast Stations, 11.45 p.m. to 12 midnight, December 13, 1910.

clock, and receives time daily at 10 a.m. over the land telegraph circuit. It should be observed in this connection that time signals sent from Norddeich and Eiffel Tower would not be recorded on the receivers by reason of the low wave-length adjustments used—*i.e.*, about 600 to 700 metres.

For the charts shown in Fig. 5, the period from 11.45 p.m. to 12 midnight, December 13th, has been selected. The character of the disturbances observed and the conditions under which they were made at the stations selected were considered more conducive to accuracy on the whole during this period than during any other set of observations. It will be seen that there is a certain degree of similarity

in most cases, but further observations will be necessary to confirm or refute this as a general conclusion.

With regard to means of reducing interference due to "atmospherics," no special devices are at present in use at the British coast stations of the Post Office, and it is problematical whether any entirely effective arrangement is possible, for the reason that a rough, comprehensive kind of receiver tuning is essential for normal uses, in order that calls on a variety of wave-lengths from ships may not be missed. For actual reception of messages, however, the sharply tuned adjustment with variable coupling can be resorted to, and the intensity of disturbance thereby much diminished. Tuning alone does not appear to be by any means a complete solution of the problem, doubtless for the reason that most, if not all, of the disturbing impulses have no specific wave-length or frequency of their own. They appear to be due to sudden changes in the electrical state of the atmosphere (probably in the higher regions), which determine sudden changes in the electrical charges normally induced on the aerial wires. The sudden release or accumulation of a charge will set the aerial system into electrical oscillation at the latter's own periodicity. Hence the futility of tuning them out. That they are reduced by tuning and weak coupling to a greater extent than signalled impulses is doubtless due to the damping factor of the aerial system, which determines a rapid rate of decay and few oscillations for the individual disturbance, whilst the signalled impulses may consist of much longer trains of oscillations.

Various devices have been proposed from time to time for eliminating or reducing these interferences, but, so far as the author is aware, the degree of success attained is not greater than is possible by the use of sufficiently light coupling combined with a "detuning" of the aerial carried out on the following lines :—

First Operation.—Reduce the coupling of the receiver to a minimum for good strength of signals having all circuits well tuned.

Second Operation.—Throw the aerial circuit out of tune (preferably on the short-wave side) as much as possible consistent with preserving the signals well above the minimum readable strength.

Third Operation.—Increase the damping of the aerial system (by suitable resistance inserted) to as great an extent as possible without reducing the signals below readable strength.

This procedure ensures heavy damping of oscillations generated in the aerial itself together with a distinct difference in wave-length between such oscillations and the signalled impulses. The aerial damping may preferably be obtained by the use of a sufficiently long and light aerial to be used for receiving only. The extent to which this method will reduce interference has not yet been fully investigated.

It is claimed for the Marconi semi-directive aerial that interference from atmospherics is reduced, but the author has no first-hand information on the point. The non-earthed directive aerials can certainly be arranged so that interference is very greatly minimised. As regards

"bridge" and "differential" interference preventers the author is of opinion that no more can be effected than by the light coupling and detuning outlined above.

The comparative immunity of wireless stations from actual damage by direct lightning flashes is rather striking in view of the exposed positions and nature of the constructions. On the few occasions on which there are authenticated instances, the damage has usually been slight, and nothing very alarming has occurred within the buildings. At the same time, it is considered policy to provide suitable means of earthing the aerial systems externally and shut down stations during the prevalence of thunderstorms in the immediate neighbourhood.

Perturbances of Wave-propagation Efficiency of the Dielectric Medium.

Wireless "freak" communications are wrapped up in the phenomenon of variations in the transmitting efficiency of the atmosphere. Perturbances in this respect exhibit almost the same characteristics of irregularity as atmospheric impulses. Freak ranges of communication or variations in range of communication occasionally occur by day, but are not (in the case of comparatively short-range coast stations) then of a pronounced character. The variations noticed during the night hours are much more pronounced. The sudden veiling or obscuring of distant signals together with the equally sudden "opening out" of signals observed whilst listening on the receiver at a wireless station during the prevalence of this phenomenon is very impressive. These variations of range are not found to synchronise definitely with the periods of atmospheric disturbances, though it may well be that more disturbances are observed when the range extends. The author has, however, noticed these remarkable variations in range on nights when "atmospherics" have been conspicuously absent. Communications taking place at ranges of less than 100 or 200 miles appear to be rarely, if ever, influenced by this phenomenon in these latitudes, and it does not therefore greatly concern the working of coast stations.

It appears probable that the phenomenon is closely connected with changes of an electrical nature occurring in the upper regions of the atmosphere, and the author ventures to suggest as a possible clue that the effective receiving range of a station is determined, not so much by the height of its aerial system, as by the height from which it will experience inductive influence, or, in other words, the height to which the lines of electric strain emanating from the aerial under the influence of the atmospheric potential gradient will persist. This, however, is at present but a purely speculative explanation.

APPENDIX I.

OBSERVATIONS OF ATMOSPHERIC DISTURBANCES AT....................... WIRELESS STATION FOR THE WEEK ENDING DECEMBER 17, 1910.

Instructions.—The observations to be taken daily from 6 to 6.15 p.m., and 11.45 p.m. to midnight, and to extend over a week, the first observations to be taken from 6 to 6.15 p.m. on Sunday, and the last from 11.45 p.m. to midnight on Saturday.

A separate sheet is to be used for each period of observation, and the date and name of the station should be inserted at the top of the page.

The magnetic or other detector is to be placed directly in the aerial; no other inductance or capacity is to be in circuit. Where a multiple tuner is fitted the "stand-by" side should be used, the aerial tuning condenser turned to "short circuit," and the aerial tuning inductance switch on the first stop. The magnetic detector should be fully wound up at 5.55 p.m. and 11.40 p.m.

Each individual impulse should be recorded by a stroke in column 2; a series of five impulses will occur so, **11111**. Any disturbances which are not distinctly separate impulses, that is, when there is not a distinct interval of silence between them, should be recorded as one impulse only. In no case is a disturbance to be recorded unless it is judged to be at least as strong as readable signals. In the remarks column the character of the disturbances should be given; it should be stated whether they are weak, mild, medium, strong, or very strong, and in connection with all of these whether they are continuous, semi-continuous (*i.e.*, have a tendency to continuity) or discontinuous. Any individual disturbance of a special nature, either in respect of its strength or character, should be indicated by a dot above the stroke so, **1$\dot{1}$1**, and an explanatory remark made in the remarks column.

The combined forms should be returned with this instruction sheet attached to the front on December 19, 1910, one copy to the Engineer-in-Chief, London, and the other to the Inspector of Wireless Telegraphy.

DISCUSSION.

Commander Loring.

Commander F. G. LORING, R.N.: I have very little to add to Mr. Taylor's very exhaustive dissertation, but I should like to call attention to two points which interest me very much. One is with reference to his section headed, "Mutual Interference between Stations," and the other, "Atmospherics and Freaks." In regard to my first point—a very practical one, I think, which should appeal to everybody who is interested in wireless telegraphy and its development—Mr. Taylor does not make any reference to the engineer who installs the apparatus, or to the operator who works it. If ships are equipped according to the standard required of them by their licence to-day, there is no reason why there should be any interference

APPENDIX II.

Observations of Atmospheric Disturbances at Radio-Telegraph Stations. December, 1910.

Date	December 11th.		December 12th.		December 13th.		December 14th.		December 15th.		December 16th.		December 17th.	
Time	6 p.m.	11.45 p.m.	6 p.m.	11.45 p.m.	6 p.m.	11.45 p.m.	6 p.m.	11.45 p.m.	6 p.m.	11.45 p.m.	6 p.m.	11.45 p.m.	6 p.m.	11.45 p.m.
Hunstanton ... (Norfolk)	0	30 Mild to Weak	37 Str. Cont.	102 Var. Cont.	58 Mild	88 Med. to Str.	6 Weak	65 Var.	0	0	44 Var. Some Str. and cont.	0	0	1 Str.
Caister ... ... (Norfolk)	6 Weak	0	123 Mild Dis.	109 Mild Dis.	71 Mild Dis.	92 Med. Dis.	0	79 Mild Dis.	1 Mild. Dis.	11 Weak Dis.	12 Weak Dis.	2 Weak	Busy	7 Weak Dis.
North Foreland ... (Kent)	6 V. Weak Dis.	—	133* Med. Dis.	169 Med. Semi.	100* Med.	95* Med. Dis.	18* Med.	104 Med. Dis.	0	0	0*	0	0	34 Mild
Niton ... ... (Isle of Wight)	13 Weak Dis.	29 Var. Dis.	359 Med. Semi.	165 Mild Semi.	Station Action	out of	Station Action	out of	0	24 Weak	0	11 Mild	0*	0
Bolt Head ... ... (Devon)	17 Weak Semi.	103* Mild Semi.	182* Var. Cont.	140* Var. Semi.	62* Med. Semi.	116 Var. Str. Semi.	24* Var. Str. Semi.	104* Var. Str. Semi.	0*	Jammed	0*	32* Weak	Jammed	Jammed
Lizard ... ... (Cornwall)	8* Weak Cont.	20* Var. Semi.	33 Mild Cont.	91* Str. Cont.	Busy	Busy	34* Str. Cont.	79* Str. Cont.	Busy	Storm	Busy	Busy	Busy	1 Mild
Seaforth ... ... (Liverpool)	0	0	Cont. V. Str.	121 Med. to Str. Semi.	0	63 Var. Str. Semi.	24 Mild Semi.	53 Var. Semi.	8 Mild Semi.	55 Var. Semi.	0	42 Mild Semi.	0	11 Mild Semi.
Malin Head ... (Ireland, North)	0	0	88* Mild Semi.	16 Weak Dis.	46 Mild Semi.	29 Mild Semi.	73* Mild Semi.	74 Med. Semi.	0*	19 Weak Dis.	0	131 Weak Semi.	25* Weak Semi.	20 Weak Semi.
Rosslare ... ... (Ireland, S.E.)	0	20 Mild Semi.	140 Almost Cont.	125 Med. Dis.	26 Mild Dis.	127* Med. Semi.	47 Med. to Str. Dis.	69 Mild Dis. Some Str.	5 Weak	2 Weak	6* Weak Dis.	1 Med.	2 Weak	2 Weak
Crookhaven ... (Ireland, S.W.)	Jammed	56 Mild Semi.	150 V. Str. Cont.	79 V. Str. Semi.	26 Mild Semi.	67* Med. Semi.	Busy	Busy	20* Mild Dis.	Storm	Storm	52* Med. Semi.	10 Mild Dis.	24* Mild Dis.
Tobermory ... (Scotland, West)	—	—	25 Str. Semi.	—	28* Med.	—	6 Med.	—	0	—	0	—	12 Weak	—
Lochboisdale ... (Scotland, West)	—	—	V. Slight	—	2	—	0	—	0	—	0	—	0	—

Explanation of Table.

The attached table shows the number of atmospherics observed at twelve coast stations in the British Isles (1) between 6 p.m. and 6.15 p.m., and (2) between 11.45 p.m. and midnight during the week December 11th to December 17th, 1910.

In the cases marked thus * the stations were busy or jammed during part of the time of observation, and the figures given have been proportionately increased. Where a station was busy during the whole period no figure is given.

As regards the notes under each figure, these refer to the strength and nature of the disturbances, and the distinctions noted are as follows: *Strength*—Very Weak (V Weak), Weak, Mild, Medium (Med.), Strong (Str.), Very Strong (V. Str.), Variable (Var.). *Nature*—Discontinuous (Dis.), Semi-continuous (Semi.), Continuous (Cont.).

Commander Loring.

between the 600-metre wave-length and the 300 at a range of 3 miles. In practice, these two wave-lengths should be absolutely independent of each other in respect to traffic. Without doubt, also, we ought easily to get another independent wave-length under 300 metres—and, perhaps, one also about 450 metres, under favourable conditions. These results should be obtained with any of the existing standard apparatus now on board ships. In practice we do not take much advantage of these facilities except in special cases, for this reason, that in the first place the apparatus is not always properly installed; and, secondly, the operator is not, generally speaking, competent to take advantage of it, even if it were properly installed. Last week I gave instructions at one of our stations in the Channel to observe the wave-lengths taken of several convenient ships that passed, quite independently of who equipped them or who installed them. The ships were nominally fitted with 300- and 600-metre wave-lengths. Thirteen ships were reported by the officer. The wave-lengths were measured on a Marconi multiple detector. The results came out as follows: 2,020 ft., 1,500 ft., 1,968 ft.—that is right; that is 600 metres, viz., 2,200 ft., and 1,670 and 1,968 ft., the two distinct wave-lengths given off simultaneously by a tight coupling—1,200, 1,200, 1,380. Then comes a ship with 1,000 ft., which is again correct; then one of 1,817, 1,830, 1,930, 1,968—which is correct—and 1,520. So that however good the design of the apparatus may be, if it is not properly installed we get all manner of wave-lengths given off, with the result that no amount of tuning skill at the receiving station will really prevent interference. I would like to add, however, that in the last two years there has been a very great improvement in the fitting of ships, and that new ships equipped are usually found approximately correct in their transmission. Most of them come out within 5 or 6 per cent. of each other. Another difficulty we have to encounter is with regard to the operators. There are some good, some mediocre, and, I am afraid, a good many bad ones. This is due to the very great development in the last year of wireless telegraphy. So many ships have been fitted that it has been found impossible to get experienced operators for them all. In my experience, if you take an ordinary expert inland telegraphist and teach him wireless telegraphy, and let him get his certificate of proficiency, he will require a year's practical experience before he is really fit to be turned loose as a wireless operator in an organisation. Probably at the present moment there are a great many men at sea who by their ignorance defeat all the regulations and engineering devices which have been brought out to prevent interference. At the same time, the ship operator has my sympathy. Let no one think that maintaining and operating a set of apparatus on board ship is devoid of toils and worries. There is often a great deal of noise, especially in bad weather. There are slack ropes and stays which, especially in bad weather and at night, rub against the aerial and earth it, unknown to the operator. There is sea-sickness, and there is the fact that the ship operator has no one of whom he can ask advice. On the other hand, I do not think that wire-

Commander Loring.

less operating on the whole demands any very special aptitude, if we except good hearing, on the part of the individual, although it does require some special training and a certain amount of practical experience. It is only a matter of time for the supply to arrange itself to the demand. It may, however, be accepted as an axiom that the more general the use of wireless telegraphy on board ship becomes, the more necessary is it that all operators should be duly qualified. One really bad operator can make an infinity of trouble in such a place as the Channel, for instance. My own opinion is that the apparatus now supplied to ships is in advance of the men who have to use it. So far as ship-to-shore work is concerned, the apparatus must necessarily remain very simple, and any immediate improvements should take the line, I think, of greater simplicity and greater reliability, especially as regards some of the detectors which are now in use. One of the great sources of trouble in certain installations lies in the receiving apparatus. An operator will never believe his own apparatus is wrong; he always believes it is the other fellow's. We have constant examples in working ships in the Channel of operators who call, and call, and call, and who disturb the working of everybody else within 100 or 150 miles because they cannot hear the replies made to their signals. There is one other improvement which I should like to see generally introduced, and which would help all operators, and that is a musical-note transmission. It is the almost undivided opinion of all the operators I have spoken to that a musical note would help them very much indeed, both as regards interference and as regards general facility in handling traffic. The note, in my opinion, should be capable of varying pitch, and its timbre should be aggressive, like the sound produced by a brass instrument as opposed to the soft, clear note of a flute; the latter is, in the opinion of operators who have heard it, not so desirable as one which possesses overtones, or has a distinct sound of aggression—a jar. All the operators at the shore stations agree that if the ships were fitted—or at any rate the more important ships—with a musical note, it would very much assist traffic. I agree with Mr. Taylor that some means of varying the strength of signals is desirable, and I think the idea of a variable coupling is a good one, especially in connection with the device we use in our own stations, namely, the Marconi type of high-frequency transformer. I do not believe, however, that at present the indifferent operator would make any use of such a device. The worse the operator, the more he clings to all available power. The same observation applies to the multiple tuner. It is a most excellent instrument, and the operators at the shore stations use it a great deal, but I have talked with and examined a very large number of operators employed on board ships, and find that the percentage who really understand the use of the multiple tuner is a very small one. I should like now to refer to the question of atmospherics, because I have collected notes on atmospherics for several years. Every month I used to have returns sent in, and the following is simply a summary of what has been reported :—

Commander Loring.

1. The worst months for atmospherics are generally May to October, especially June, July, and September.

2. The fewest atmospherics occur during the months of January, February, and March.

3. The worst hours of the day for atmospherics are those between sunset and sunrise. The disturbances are usually most pronounced soon after sunset and die away towards dawn.

4. The period from sunrise to noon is generally that freest from atmospherics.

5. The following table shows the prevalence of atmospherics at a certain station in the English Channel for one year :—

	Moderate Hours.	Strong Hours.	Violent Hours.	Total Hours.
January ...	—	—	½	½
February ...	—	—	1	1
March ...	—	2	—	2
April ...	18¾	3	13¾	35½
May	17	43	60	110
June	13	46½	17¼	76¾
July	44	52	53	149
August ...	20	51	71	142
September ...	27	42	94	163
October ...	63	25	71	159
November ...	15	18	2	35
December ...	4	3	2	9

Moderate.—Signalling not affected on tune side of Marconi multiple.
Strong.—Signalling difficult.
Violent.—Signalling practically impossible.

6. Heavy rain is accompanied by atmospherics. Hail and snow by atmospherics of a very distinctive type, which cause a hissing sound like escaping steam or a violent pattering sound in the telephone receivers. The advent of a storm is usually heralded by atmospherics, and atmospherics often accompany wind from a particular quarter. Easterly wind has been noticed as having a pronounced effect on atmospherics at the wireless station on the East Coast and N.W. winds in the case of stations in Ireland.

7. Atmospherics are much more pronounced on long wave-lengths than on short ones. Observations on wave-lengths of 15,000 to 20,000 ft., for instance, are much more interfered with by atmospherics than observations on 2,000 ft., although the relative strength of the observed signals and the actual external aerial employed may be the same in each case. Using two stations in the same locality, one working on 2,000 ft. and the other on 15,000 to 20,000 ft., the relative hours of disturbance from atmospherics has been reported to be as much as 1 : 10.

Commander Loring.

8. Atmospherics also seem to occur on definite wave-lengths to some extent, and I have known it possible to get communications through by a considerable alteration of the wave-length at the transmitting station.

9. The prevalence, or otherwise, of atmospherics does not appear to bear any relation to the appearance of freak signals. At any rate, atmospherics have been reported by reliable observers to be least noticeable at periods of freak ranges.

10. With regard to the effect of atmospherics on actual working the following observations made by the officer in charge of Crookhaven are very typical. He says: "It is often necessary on account of atmospherics to give ships 'wait' until signals improve. Occasionally even when signals are strong working has to be entirely suspended owing to heavy and continuous static discharges from the aerial. These discharges last from a few minutes to almost an hour, and are particularly prevalent during hail and snow squalls."

11. With regard to "freak" signals, in my experience they occur always at night. The Post Office station at Hunstanton is remarkable for its experiences, and it is notable that the mast is only 120 ft. high.

This station sometimes hears a ship station to the westwards of Crookhaven lose touch with the latter, as the ship proceeds westward, the signals at Hunstanton still remaining strong. The best freak range noted by Hunstanton was from a ship 2,800 miles to the southward (300 miles south-west of Cape Blanco in Africa), but it is only a freak of course. Another curious point in connection with freak ranges is that North Foreland, Bolt Head, and Crookhaven have never intercommunicated, or only extremely rarely, and yet all of them can frequently intercommunicate with ships in the Mediterranean at night. These signals from the Mediterranean are often as strong as those of ships only 20 or 30 miles away. There are three stations on the Morocco coast which at times have seriously interfered with the traffic in the Channel at night. They have been known absolutely to jam the traffic off Crookhaven, and these facts are rather interesting, since they demonstrate that in considering the scheme of a commercial organisation of stations whose day range is only about 200 miles we must bear in mind the fact that the effective range at night of these stations may be five or six times as great. Consequently it is of great importance that all stations, even those in remote situations, should be "syntonic" in the sense given to the word by the licence, that is to say, "Apparatus shall be deemed to be 'syntonised' when the transmitting apparatus is so adjusted as to communicate with a receiver which has a corresponding adjustment and to produce as little effect as possible on a receiver not having a corresponding adjustment." Judging by the wide range of tuning over which the interference is observed from many continental stations, one is forced to the conclusion that the practice in this respect falls very far short of what is either possible or desirable.

Sir Oliver Lodge.

Sir OLIVER LODGE: Will you allow me in the first instance to say, sir, what a pleasure it is to me, owing to our very early connection about half a century (more or less) ago, to see you in the chair. Next,

Sir Oliver Lodge.

I trust it is not impertinent to congratulate this Institution upon getting the benefit of the very valuable experiences obtained by those in authority at the Post Office—and in saying this, I am referring not only to Mr. Taylor's paper, but to the recent valuable one also of Major O'Meara. It seems to me that it has not always been that we have had papers thus communicated; but in that way we obtain information which it is hardly possible for private people to collect. There are one or two observations that I should like to make. Perhaps it is known to some here present that I am in town on other business, and since that other business is *sub judice*—or indeed in any case—I should be very loath to say anything that can even appear, in the remotest way, to bear on anything which was raised in that connection. But there are certain observations of interest to me in Mr. Taylor's paper; indeed, the whole subject of interference is of great interest and must be of very practical interest to everybody connected with wireless telegraphy. It seems to me at present that most practical working is very largely dependent on the skill of the operators. Commander Loring with his great experience says that operators are pretty bad, but some of them appear to me to be extraordinarily good. I suppose he will admit that. [Commander LORING: Quite so.] The way they pick out the message they want to attend to in the midst of a perfect babel of other communications strikes me as very skilful; it is like trying to carry on a conversation in the midst of a conversazione. They manage to do it in peace-time, but what will happen in war-time—when everybody is far from trying to give way and be polite to others, but is trying to disturb everybody else—I really do not know. And I do not think myself that the Admiralty ought to be satisfied with that dangerous state of affairs. I should very much like to take the opportunity of asking Commander Loring, with his experience of ships, whether there would be insuperable objection to a lower capacity aerial on a ship. Every one knows that at the top of the masts there is what may be called a capacity aerial, but I understand the custom is almost universally for the lower aerial to be the earth—that is, the sea. Now my experience of ships is practically nothing; my experience has been mostly gained on land. We find that when we are using the earth, the actual earth, as the lower capacity aerial, we are spoiling the tune; we are putting, as it were, dirt into the oscillating system—soil. The oscillations come down from the upper metal and get lost in the soil. And even the upper aerial is found best to be of a certain shape. We tried a lot of networks and all sorts of things at first, and Dr. Muirhead ultimately designed this kind of Maltese-cross arrangement which we now employ. Now, why is such a design an advantageous shape? I confess the advantage of it rather surprised me. If we join up the corners, it is not nearly so good. It is far better than a grid or a closer kind of framework of wire. Why? Well, I think for this reason—because the surge going up into it finds itself at the centre with a number of equal alternative paths, a definite number of destinations, equidistant in every case—that is

Sir Oliver Lodge.

my assumption as to the reason—so that the up-rush arriving by the central lead piles itself up to a maximum potential *there*, then rushes back again, being reflected, each by an equal length of path, so that all the passengers, so to speak, arrive at the junction together, and go down together in one complete rush of considerable intensity. But if you have a more ordinary sort of shape, like an ordinary framework or grid, there would be many places or destinations where they might go to before reflection, and they would come down back again in a procession, not in a clump, and there will be a dribble instead of what is really wanted.

Now take the lower aerial. We make it the same, so that the charge reverberates up and down for a fair length of time. But if it is put to earth what happens? The pulses go to various depths in the earth—they go trapesing about in a bad conductor, which sometimes is very bad and sometimes is less bad; and they are liable to encounter different soils or conditions of varying moisture—the result of all which is that if they return at all they come back, not in a clump, but in a procession. But they do not all come back. The energy is dissipated by the bad resistance of the earth, however good in reason the earth connection is made; at any rate, our experience is that the tuning is not gone altogether, but greatly lessened—its sharpness is gone. Whether that is so at sea, where instead of dirt there is salt water, I do not know, but the experience recorded in this paper of Mr. Taylor's suggests that everything is not right and that there is something which might be done to get much better tuning. I feel bound to refer to the difficulty experienced in tuning-out according to present official practice. I am not speaking of anybody in particular, but present practice generally. Let us take an Admiralty station and a Lodge-Muirhead station. We at the latter place can tune the Admiralty out with perfect ease, but in some cases the Admiralty cannot tune us out. They say it is our fault, but I suggest that it is partly theirs.

Nevertheless Mr. Taylor's remarks on the difference between what he calls a pre-charged system and a system charged by sympathetic resonance worked up by a closed-circuit arrangement, in connection through a transformer with a radiator, are very interesting—the same thing very likely being used as a receiver. He points out that in that case there is no pre-charging, that the rushes and surges begin gradually to work up, and that there is no great electrostatic influence, initially, before the spark occurs. The spark occurs at a time when the aerial is not charged, and it is only charged in the course of its oscillation. That is quite true. He thinks the difficulty of tuning us out is because of our pre-charging aerials, whereby we exert an electrostatic inductive effect on other stations in the neighbourhood. Professor Tyndall used to call it, in connection with lightning, Lord Mahon's returning stroke; that is to say, when there was a flash of lightning in one place, the cloud by hypothesis being charged, all conductors on the earth below that cloud had their induced charge suddenly liberated; so that the released

Sir Oliver Lodge

induced charge went down and did damage. That was the theory, and that appears to be in essence Mr. Taylor's theory of our disturbance. Well, I always doubted that theory, because if we come to consider how much electrostatic energy there is thus stored in the things under a cloud, and what the effect of liberating the little bit of an induced charge would be, it would be enough to affect an electroscope or a delicate galvanometer, but it could not do any damage. That, however, is not now the question; the question is not whether it will do damage, in a lightning conductor sense, the question is whether it will affect a coherer. Understand, I am chiefly throwing doubt upon the explanation. It does not much matter perhaps what the explanation is, but it is interesting to know. I suggest that a coherer is only likely to feel the effect if the collector itself is rather an untuned thing. If we use as collector a damped vibrator it will certainly pick up any kind of disturbance that is going on, freaks and atmospherics and everything else, and bring them perilously near the coherer's circuit. That circuit, no doubt, is properly tuned, but any tuned circuit will respond to disturbances of sufficient vigour. Every one knows that one tuning-fork will make another respond if they are of the right note, but that does not prevent a tuning-fork from responding if it is hit. Now the freaks and violent disturbances do hit the coherer's circuit through its untuned collector.

Our own collectors are not untuned, they are themselves fairly persistent vibrators, and the result is that we can tune out our own stations with perfect ease, even if they are quite near each other. We have carried out experiments with regard to two stations in adjacent fields. Mr. Taylor, I think, has seen it, and perhaps he will verify what I say. Suppose there are two adjacent stations, one speaking to a distance and one listening to a distance, then the latter is able to tune out the former and not hear it, though it is shouting in its neighbourhood, and yet all the time it is listening to signals coming from a long way off. That is the severest test of tuning that can be had, and another is this: We can split the upper aerial into two and bring down two wires to two lower aerials and two receiving sets, putting a little different self-induction into the two—and then we can listen with half the aerial to one set of signals and with the other half to another set of signals. In fact, we can get diplex telegraphy, not duplex. I should be very sorry, however, to attempt any of those things if we had an earth connection. We do not necessarily use a closed resonating circuit, because we have a collector which is itself accurately tunable; and I see certain advantages in that. We have then only one thing to tune, and it will not respond easily to anything except its own note. Therefore it is not so liable to bring foreign disturbance near the coherer, but picks up what is wanted.

Mr. Duddell.

Mr. W. Duddell: The first point I should like to refer to is the question of the amount of power we are using in wireless telegraphy. I feel we are working on wrong lines; that we are trying to work and receive signals with too small a power. Let us think what would

Mr. Duddell.

happen supposing we all started using, from to-morrow, ten times the amount of power in our transmitters and in our receivers. What would be the interferences? "Direct interference by extraneous sound and noises." What would be the importance of the extraneous noises if we had ten times the strength of our signals to deal with? Practically nil. We could work under conditions which we now cannot think of. Then "Electrical interference by local induction influences." Those would practically vanish. "Electrical interferences by waves from other stations." Well, if all stations were able to get ten times the present strength, they would be exactly in the same ratio as they are now, so that by using less sensitive detectors—detectors that were much more suitable and perfect in their action—we should be in the same position as we are now. "Atmospheric electrical perturbations." Where would they be? We have heard to-day from Commander Loring that there are 670 hours of interference in the year. That figure of 670 would probably drop to 6 or 7 if one had ten times the strength of signal. "Perturbations of wave propagation efficiency of the dielectric medium." If we had ten times the strength of signal to deal with, then we could, in the case of a reduction of the efficiency of transmission due to atmospheric causes, overcome that difficulty by using the sensitive detectors we now possess. So that I think the great thing we want at the present moment to aim at is to get more power in our transmitters and more received current in our aerials. I fear the present rules and regulations which tend to tie us down and make us use less and less power in our transmitter are really in the wrong direction. The present method corresponds to working an ordinary land line with a fraction of a milliampere. It is marvellous the result we get with the extraordinarily small amount of energy we have in our receiver. I believe the actual amount of energy we are now working with in our receiver is a fraction of a micro-watt, and we are expected to make sensitive instruments record and even to write down the signals. I do not think the position is a very practical one for the future of wireless telegraphy. We want more power in our receivers, and there seems no difficulty in obtaining it in view of the improvements that have been made in transmitters of late. Coming to the question of the coupling of the detectors with the oscillating circuit, Mr. Taylor referred to the 3-circuit receiver (multiple tuner) of the Marconi Company. I have always had a great difficulty in seeing where the advantage—the theoretical advantage I mean—comes in in multiple-circuit receivers. As far as I can see, what is really wanted in order to get good tuning in the receiver is to have the receiving circuit—which is the aerial, and a very freely oscillating circuit—a conserving circuit. Some means is also wanted of connecting the detector to this latter oscillating circuit so that the detector itself shall not introduce too much damping into the oscillating circuit. That, as far as I can make out, is really all that is done in the multiple-circuit systems. They are really convenient methods of uncoupling the detector, which is the thing which requires

Mr Duddell.

energy to work it, from the freely oscillating circuit, and it is uncoupled just to such a degree that it does not interfere too much with the free swinging of the oscillating circuit. There are a great many devices for doing this. I think any means by which it is possible to uncouple the detector—which is an energy-absorbing device—from the oscillating circuit will tend to give sharper and sharper tuning, and that this is really the whole function of the multiple-circuit tuners. With regard to atmospherics, a most interesting question arises: Do these atmospherics propagate themselves with the velocity of light, and if so can we predict in any way the direction from which they are coming? It seems possible—I think all the experiments on measuring the velocity of light have been carried out over distances of only a few miles. We are dealing with disturbances that can be detected and recorded over distances of 1,000 or more miles. What I should like to ask is, Is it possible to determine the differences of time between the arrival of an atmospheric at two points, say, 1,000 miles apart? This may seem difficult at first sight, but it seems to me that if we could send off from a transmitting station, say a dot, somewhere in the neighbourhood of the time an atmospheric takes place, and record the atmospheric and the dot at two receiving stations, say, 1,000 miles apart, and then at the next atmospheric repeat the experiment in the opposite direction, we might find a difference of time which would give some indication of the rate of propagation of the atmospheric. The differences would only be in the order of 1/200 of a second for 1,000 miles. If we could get a record we might form some idea as to the direction in which the atmospheric is coming. I do not know whether such an experiment is practicable, but with the enormous distances we are now working with there is quite an appreciable time to deal with. I understand that the long wave-lengths are very much more troubled with atmospherics than the short ones, and I should like to ask whether that applies to a comparison of a station with a short aerial or with a station with a large aerial, or whether it applies to the same aerial used for both waves. One can see that the station with a very large aerial will be liable to pick up atmospheric disturbances, but one does not at first sight see why a station with a medium-sized aerial should pick them up more when self-induction is put in series, and the aerial is therefore given more electrical inertia.

The question of the pre-charge of the aerial has been raised by Sir Oliver Lodge. There is no doubt about the fact that the pre-charged aerial does tend to upset the ordinary coupled receiving station; but, on the other hand, the Lodge type of aerial, which has an insulated lower capacity, that is, practically two aerials one over the other, seems to be able to tune-out the ordinary station extremely well. Now, is that in any way connected with the shape of the waves used in the two systems?

I think the upper and lower capacity connected together by a self-induction form an extremely good oscillator, the current in which will oscillate as shown in Fig. A. On the other hand, the coupled

Mr. Duddell.

circuit produces oscillations in the aerial as shown in Fig. B—I am supposing a very small coupling so that I have no beats. The first swing of the directly charged aerial is a very large one, the coupled aerial never attains such a large amplitude. This may be a part of the explanation, but it does not seem that it can quite account for the whole thing. What we have to look at is, when we come to get an aerial with a large amount of inertia—a self-induction between an upper and lower capacity—and we act on it with a force with a

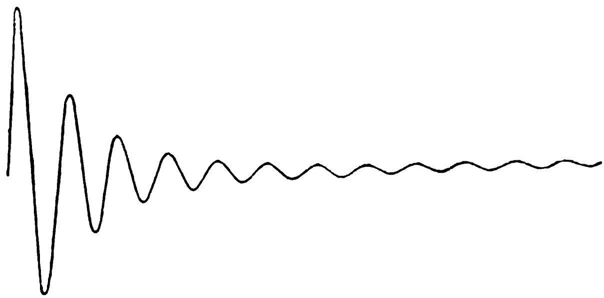


FIG. A.

small amplitude which is received from a coupled transmitter, if the frequency of that small force is not quite right, it will not set up oscillations in the high-inertia Lodge type of aerial, so we can tune it out. But take the other way round; take the reaction of Fig. A type of wave on a coupled receiver. Most of the coupled receivers are generally coupled moderately tight. We cannot work them too loosely or we should not have enough energy. In the first one or two swings quite a considerable amount of power is received by the receiving aerial,

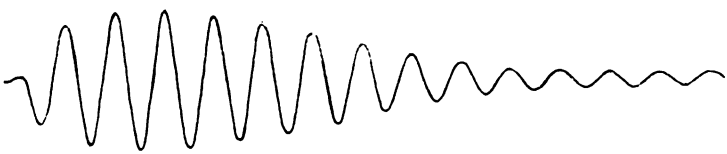


FIG. B.

and it is sufficient to produce by shock an oscillation in the coupled circuit which produces a signal; thus, I think, the coupled receiver is not able to cut this out; but the Lodge aerial is quite well able to tune out the waves emitted by a coupled transmitter. I do not know whether Sir Oliver agrees that this is the explanation of the real reason why the pre-charged aerial does seem to affect the receivers of the coupled type more strongly than others. I quite agree with Sir Oliver that the direct electrostatic action cannot be the real explanation, as there could not be expected to be any appreciable direct electrostatic action over such distances as a mile or two.

Sir Oliver Lodge.

Sir OLIVER LODGE: I am much obliged to Mr. Duddell for his remarks. I think he has given the right explanation. Possibly it is the same explanation as Mr. Taylor intended to indicate in his paper. One of Mr. Taylor's explanations of the difficulty of tuning us out is that the vibrations in a Lodge-Muirhead system are of a more "forcing" character than those which he prefers. They begin at the maximum, he says, whereas his kind begin working up, and so give a gentle, flute-like variety, whereas ours have a more sharply trumpeting variety. He calls that more "forcing." Very well; but what do you want if you wish to speak to a long distance? It is no great advantage to be able to whisper; you want to shout. It is possible that ours may be rather harder to tune out, as Mr. Duddell has said, by means of any collecting arrangement which would emit the flute-like kind and which is susceptible to shock. I have had no experience of gigantic distances, like Mr. Marconi, but our practical experience certainly is that the Lodge-Muirhead system is very efficient for what I may call considerable distances. I may say that because the statement has been published by the Indian Government. They signal regularly—and have done for years—from Burmah to the Andaman Islands, 300 miles, with no necessity for more than ½ H.P.

I was a little surprised at what fell from Mr. Duddell about the advantage of using very great power. I would prefer to see accurate tuning and moderate power. I do not like the idea of everybody shouting at the top of their voices, and so wasting energy, or at least not using it. I would rather use all the energy and receive it in the right and desired way. In that part of the world between the Andaman Islands and Burmah I cannot imagine there is much interference; certainly I have not heard the Indian Government say so—perhaps that is why they need not use much power—but they report rather enthusiastically about the steady working of this arrangement with extraordinarily little power and trouble.

Communicated: It is historically interesting to realise how very recently the importance of self-induction as a factor in electrical work has come into prominence. The name was introduced by Clerk Maxwell, the idea having previously been introduced by Kelvin as "electrodynamic potential," and by Neumann as "Selbstpotentialskoeffizient," but for a long time the idea was one of felt difficulty and was only used by physicists—being as a matter of fact rather scouted by some practical electricians and telegraphists. Thus, for instance, Sir William Preece is reported in the *Electrician* or *Electrical Review* of 1888, to have spoken of it humorously as a "bugaboo"—a sort of bogey with which physicists were trying to worry practical men. Its use for filtering out rapid oscillations from steady currents and sending them *viâ* a spark-gap or other obstruction while the steady current went round what is now called a choke coil, though known for regularly alternating currents, was introduced, as respects sudden rushes or groups of oscillations in my "lightning guards," described to this

Sir Oliver Lodge.

Institution in the year 1889*; and the combined use of self-induction and capacity for tuning purposes and the obtaining of sympathic resonance was not by any means widely or generally known, even up to the nineties, so that when an effect was observed in the Deptford mains—an effect designated by the name of our President, "the Ferranti effect"—it was not at once understood by engineers who did not happen to be also physicists, though it was soon explained as an interesting occurrence of sympathetic resonance at a certain frequency, owing to the combination of self-induction and capacity. The easy way in which tuning devices are now applied, both at the sending and receiving end, for wireless telegraphy, indicates the rapid development which is characteristic of our science on its practical engineering side. The term "inductance" itself was indeed coined in quite recent years by Mr. Heaviside, to bring it into line with the word "resistance," and prior to that no one could have spoken of "an inductance of so many henries" with any chance of being understood; the term "secohm" and the term "Quadrant" had been used to a limited extent in the same sense previously, and instruments for measuring inductance were by some of our past and present members being devised, but the term "henry" was adopted at Chicago in 1893. It is sometimes difficult for me to realise that I myself go back to the days when not only secohms and henries, but the much older and more familiar ohms and volts and amperes were things of portentous difficulty, requiring a lot of explanation; whereas now they are sometimes in the mouth of workmen engaged on an electrical street job. The fact is that the measurement, and the effective dealing for engineering purposes, of such unknown and novel entities as electricity and magnetism even now still are, is an advance which has demanded the highest genius; and we are now standing on the shoulders of giants of the Victorian Era, of whom, in our country, Kelvin and Maxwell must be recognised as chief; and the everyday application of their great ideas to practical purposes is continually on the increase.

Dr. Erskine-Murray.

Dr. J. ERSKINE-MURRAY: I should like to say first of all how pleased I am to see some substantial facts in these matters coming from Mr. Taylor after such a series of interesting experiments. But to come to points of theory, I do not think Mr. Duddell has drawn his diagram quite properly. I may say I am not basing this entirely upon theory; but mainly upon an experimental fact that I noticed twelve years ago when I was in charge of the Marconi Station at Chelmsford. Whether we are using the interrupted current from an ordinary hammer break, or an alternate current, in the transformer as primary source of power to charge the aerial, what happens is this: the aerial voltage goes up on the low frequency, to the maximum, and then the spark occurs and a short train of diminishing waves is produced. It does not appear to have happened in practice to either Mr. Duddell or Sir Oliver Lodge to have got signals from the first maximum voltage without the occurrence of a spark, but I have noticed it dozens of times—see Fig. C,

* *Proceedings of the Institution of Electrical Engineers*, vol. 18, p. 387, 1889.

Dr. Erskine-Murray.

part of curves marked (*a*). In 1899 we were in the habit of sending long strings of V's, twenty at a time, for testing purposes. At the end of every twenty V's the operator had to signal how many dots he had missed. He knew how many he had missed by counting the number of times the spark did not occur. Frequently, when we had the string of V's perfect at Chelmsford the operator at Harwich signalled that he had missed three or four dots. We took the greatest care in the matter and we found the same happened on sending from our end. There was only one explanation of this. We were getting signals from the primary charge of the aerial before the discharge occurred. No rapid oscillatory discharge occurred at all, but simply a leakage back to earth. Mr. Taylor has spoken throughout his paper of blunt resonance curves. I do not think he has quite emphasized sufficiently, so far as I understand it, the fact that a resonance curve does not represent an impure wave in one sense of the word; that is to say, it does not represent a wave of white light.

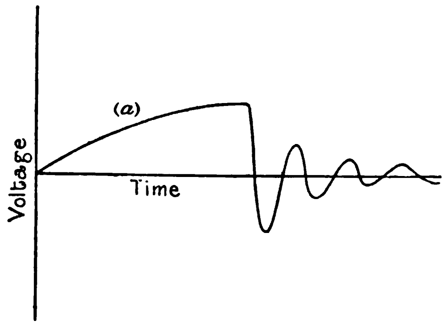


FIG. C.

Perhaps it does represent such a wave, but it does not necessarily represent a whole lot of waves with a very large number of frequencies. If we get a blunt resonance curve in a receiver it does not necessarily mean there is anything coming through space at the frequencies represented by abscissæ of the curve other than that which gives maximum current. It means only that the particular wave transmitted is of such a form that it can excite the receiver or wave-meter although their frequencies are different. Of course, that ought to be perfectly obvious, but it seems occasionally to cause confusion of ideas in papers on wireless telegraphy. In the same way, when we speak of the double frequency and get a double-peaked resonance curve (see Fig. D) what is coming into the receiver from the transmitter is, I think, only one wave of the frequency N_1 and one of the frequency N_2; that is to say, in reality, a complex vibration which can be analysed into these two waves only. When the natural period of the wave-meter is made different from either of these, a current is still produced in the wave-meter, which has the frequency N_3 of the new setting of the wave-

Dr. Erskine-Murray.

meter. There is, however, no wave of this frequency coming through space to the receiver. Under these circumstances, which are represented by any point on the resonance curve not a maximum, the current in the receiver is shock-excited by a current of different frequency to its own. The amount of such a current and the range of frequencies over which it is possible to adjust the receiver and still obtain an appreciable current induced, varies with the damping of the transmitted wave and receiver. The greater the damping, the greater may be the difference between the frequencies of the inducing and induced currents.

As to the question of close coupling and the quenched-spark methods, I have not found the quenched sparks difficult to tune out; that is to say, I have found the tuning very sharp. I need not base this only on my own observations at short distances, however, for one of the

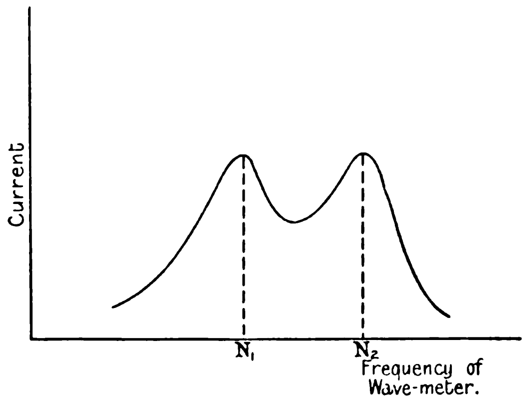


FIG. D.

officials of the Marconi Company told me a few days ago that they have had reports from their ships in regard to the Lepel station in Jamaica, and find that the tuning is extremely sharp. At very short distances I find disturbances, but at the ordinary working distance the tuning is so sharp that although the Marconi ships can always pick up this particular quenched-spark station, some of the other ships do not do so with certainty; probably there is too much damping in their receivers. I should like next to say a word on tuning with continuous waves. I think continuous waves would be an extremely good method, if it were not for the trouble in putting energy into those waves. If we could get a pure sine wave it would be all right. The trouble is that when we try to produce much high-frequency energy from an arc, it is almost essential, under present conditions at least, to force the arc by means of a blast magnet, or otherwise, but particularly by means of a transverse magnetic field. The wave-forms resulting from forcing an arc have been worked out by Barkhausen theoretically, his results con-

Dr. Erskine Murray.

firming some oscillograms taken by Blondel some years ago. They show very clearly the difference between the types of wave obtained in an arc under different circumstances, and indicate that if the arc be driven to give a large output the wave-form is very far from sinusoidal and contains a large number of harmonics which may cause interference although the tuning to each is sharp. With regard to non-earthed aerials, and particularly the triangular aerials which Mr. Taylor mentioned, it appears very difficult to interfere with them; they keep their own free oscillation most persistently. As regards the atmospherics, I believe it is a fact that directive aerials do suffer less. I would suggest that one class of atmospherics come from all directions—the wave class, and therefore a directive aerial picks up fewer than a non-directive aerial. I am waiting at the present moment for a licence from our friends in the Post Office in order that I may study this question of X's pretty thoroughly. I am going to load an aerial with large capacity, as Mr. Duddell suggested, and I think I shall be able to filter out the true radiative disturbance, avoiding local discharges, for there is not the slightest doubt that a large number of our X's are shock disturbances due to sudden discharges at a distance. I will give two instances which make it perfectly clear to my mind that the "explosive" disturbances are due to thunderstorms, or something of that nature. At the Marconi station at the Haven in 1899 there were two days on which X's were so bad that we could receive nothing at all from Alum Bay. The inker was simply chattering the whole day. We noticed on one day that, though it was a perfectly fine day at the Haven, there had been very severe thunderstorms in Northern France. Another day in the same summer, not very long after, we had the same experience—in fact, it lasted for two days this time—and then there were some extremely severe thunderstorms in Yorkshire although perfectly fine weather at the Haven. I think the connection of the two is too obvious not to merit attention, and, indeed, to prove that X's are to a large extent due to wave disturbances generated by natural causes. There is, however, another type of disturbance which seems difficult to avoid, namely, the sizzling and frying noises, the noises which are more or less continuous. These are probably due simply to ordinary brush discharges from the top of the aerial. As is known, in ordinary fine weather the variation of potential from the earth upwards is about 700 volts per foot. If there is not a very strong brush discharge going on all the time from the top of the aerial I should be very much surprised, and as that brush discharge is never absolutely regular it must be heard in the detector. [Sir Oliver Lodge: You are assuming it is earthed at the bottom?] Yes, and no doubt an aerial having no conductive earth connection would be little subject to this type of disturbance, but the other types which Commander Loring called the long wave-length stations are seriously affected. If a thunderstorm is going on and anything is struck, such as a mass of conducting cloud, or the earth, a wave is produced from a "circuit" in which the capacities are extremely large. The inductances, no

Dr. Erskine-Murray.

doubt, may be comparatively small, but the inductance of a spark 4 or 5 miles long must be considerable. Now a long-wave station will obviously be most affected by long waves even if they are very much damped. There is a possibility, as pointed out by the late Professor Fitzgerald, that we may get oscillations between the earth and the upper air if the upper part of the atmosphere is sufficiently conductive. Any discharge will excite at least parts of this great condenser, and the resultant oscillations will have definite periods. Professor J. J. Thomson has calculated the periods for such a concentric-sphere condenser and finds there are two or three classes of oscillation. There is a very long period which I find to be about one-sixth of a second; and there are a series of short periods, the wave-lengths of which are comparable to the distance between the earth and the upper layer—the longest of those is something like 20,000 metres. We may therefore be actually receiving oscillations which have a definite period, and which we may therefore be able to tune out to a certain extent. As regards the mutual disturbance coefficient, I should like Mr. Taylor to explain that definition. It seems to me an interesting suggestion, and further consideration might lead to discovery of more factors, and hence of other methods of avoiding disturbances.

Communicated: I should like to make two further observations on the subject of atmospherics. The first is as to the reality of the electric waves due to thunderstorms. Some years ago a near relative of mine was walking with a friend in Luss glen while a severe thunderstorm was raging in the neighbouring mountains but not in the glen. Suddenly both felt as if they had been struck heavily between the shoulders and each looked round expecting to see the other fall. The cause was evidently an electric shock, though no flash was seen. Had there been a wireless station within several hundred miles can we doubt that it would also have been affected? Such phenomena are, of course, well known in the country, cattle and horses being frequently killed in a thunderstorm although not actually struck by a flash. Mr. Taylor has noted that X's are more frequent in the middle of the night than at other times. The explanation of this is, I think, quite simple. In the tropics thunderstorms are of constant occurrence, thus there is always at least one thunderstorm going on somewhere within two or three thousand miles of these islands, *i.e.*, within a range at which artificial electric waves from Clifden, and even much smaller stations, can be detected, almost any day or night, by a wireless receiver. There are, for instance, on the average, fifty thunderstorms recorded at each meteorological station on the Bight of Benin during a year; the actual averages being as high as 200 per annum at Bismarckburg in German West Africa and 95 at Vivi on the Congo. As these storms, of course, do not occur simultaneously at all the stations, it is obvious that this district alone must provide a thunderstorm on nearly every day in the year. When we take this into consideration and the fact that even in Southern Europe the average, at each place of observation, is as high as thirty per annum, we see that there must be an almost

continuous succession of natural electric waves passing over this country throughout practically every day of the year; amply providing cause for all the explosive X's which are observed. The fact that X's are more numerous at night is therefore to be explained by the fact that the transmission of wave disturbances is better at night. The range over which a thunderstorm will cause disturbance in a wireless station is greater during the night, thus storms, mostly in the tropics and mainly on the West Coast of Africa, though too far off to cause X's during the daytime, produce troublesome disturbances at night. Put shortly, in the night more storms are within range than during the day. Dr. Erskine-Murray.

Since writing the above I have had an opportunity of proving definitely that the great majority of X's, at least, are caused by lightning flashes. At my station at Bushey I have observed a large number of lightning flashes with the eye, listening at the same time in my wireless receiver. I find that every distant flash observed produces simultaneously an X in the receiver, and that the single knock, double knock, and short hiss are all produced by flashes of more or less complex character. I also find strong indications that the disturbance which constitutes an X, although much damped, has a definite wave-length; a greater number being audible on a small aerial tuned to 2,000 m. wave-length than on the same aerial tuned to 600 m. I have not yet determined the longer limit of average wave-length but have noticed that the number of X's observed appears to be less when the tuning is raised to about 10,000 m.

Mr. A. S. M. SÖRENSEN: Although I have no experimental data to present in opposition to Mr. Taylor's suspicion in respect of mutual interference between Poulsen and spark stations, I should like to claim your attention for the following remarks: Mr. Taylor advocates for minimising interferences the use of loosely coupled, slightly damped receivers, and points out that for continuous-wave systems a receiver of this kind is not only desirable but necessary (to accumulate a sufficient number of oscillations), so that it is evident that the Poulsen receiver as such possesses the desirable qualities for minimising interference in a higher degree than the ordinary spark receiver. Considering the effects from the Poulsen sender, first, the comparative smallness of amplitude, which necessitates the specially adapted receiver, obviously means that a receiver not so adapted would remain much less affected. But to this comes, secondly, the continuity of the waves and the sharpness of tune. The consecutive impulses, being precisely timed by the periodicity of the sender, must on a slightly distuned receiver destroy each other's effect. Speaking of the sharpness of tune, I should like here to make a side remark as to the use of the term "undamped." It is quite true that, due to the arc being extinguished for a short interval during each oscillation, an oscillation taken singly cannot be represented by a pure sine curve, but regarding a train of oscillations, there is a distinct difference between any spark oscillator and the Poulsen arc oscillator. In the Mr. Sörensen.

Mr. Sörensen.

first case, the oscillatory discharge of the condenser causes a train of oscillations with a constantly decreasing amplitude, and when this has died out, an interval, as a rule of comparatively long duration, follows until the circuit is again excited. In the latter case, a train of continuous and uniform oscillations is generated. As now the damping is generally referred to as the proportion between the amplitudes of consecutive oscillations, the term "undamped" does not seem altogether out of place in respect of Poulsen waves. Reverting to the question of interferences, I now come to a third point. In spark-telegraphy the audible signals are produced by sending a number of consecutive wave-trains, the number being different for the dot and the dash, whilst with the Poulsen transmitter in both cases only one train (but of different duration) is sent, and as the frequency of the oscillations is too high to be audible, no signals are produced, even when the receiver is tuned to the transmitter, unless special arrangement be made for making the signals audible (as is the case with the Poulsen tikker receiver). Further, the signalling is affected by a small variation in wave-length, so that only very sharply tuned receivers could intercept the difference between signals and intervals. For these reasons I think it must be concluded that a great freedom from interferences is to be expected with the Poulsen system, and Mr. Taylor himself admits that no interference is caused by the Poulsen sender over any appreciable distance. In conclusion, I should like to suggest that when getting so far that even distances of a few miles are too long, the way out of the difficulty arising from interferences between stations would be to abandon the spark methods altogether and adopt the Poulsen system throughout.

Discussion before the Newcastle Local Section, March 27, 1911.

Professor Stroud.

Professor H. Stroud: I have to thank Mr. Taylor very much for coming up here and showing us these very interesting experiments and for bringing this matter so prominently before us. It shows that wireless telegraphy has reached a high stage of perfection when interferences can be dealt with so fully. I think that the question is a very important one, and one which, owing to the development of wireless telegraphy, has to be considered in very great detail. I am also particularly interested in the Post Office transmitting set which Mr. Taylor has put on the table. It is extremely compact and very serviceable. I may say with regard to the nature of interferences from other stations, we would have liked to have heard something more about the undamped wave system, and I hope that Mr. Sörensen will refer to it in detail. By means of the musical spark, I believe it is quite possible to hear messages even when atmospherics are fairly strong, and it is also possible to distinguish stations from each other by the note given. To a very great extent this will limit interferences, and perhaps Mr. Taylor can tell us something more about it. With regard to atmospherics,

Mr. Morris Airey and Dr. Eccles made experiments during last summer, particularly in connection with the question of varying wave-lengths and atmospherics. I think Mr. Taylor's paper is one of very great importance, because of the detailed way in which the different interferences are referred to, and the way in which they are got over by the apparatus employed. Professor Stroud.

Mr. A. S. M. SÖRENSEN: I regret that I have no facts to hand of interferences between the Poulsen system and any of the spark systems. I am not aware of any other station being disturbed by my station, and I have no figures as to the effect of the Poulsen system on spark stations. Mr. Sörensen.

Mr. H. R. KEMPE: The subject of wireless telegraphy, generally, is of very great interest to me. When Mr. Marconi came over to England, he was handed over to me to assist him in making the first experiments in England. I took Mr. Marconi with his apparatus, which was then of a rather crude nature, to the top of the General Post Office. The apparatus was installed there, the transmitting apparatus and the receiver being set up about 30 or 40 yards apart. The results were very surprising to us, as the distance spanned was very much greater than had up to then been crossed except by ordinary means. I next took Mr. Marconi to Salisbury Plain, having previously selected a stretch of country of about 2 miles in length for this purpose. We had the apparatus fitted up, and it may be of interest to state that that very apparatus is now in the museum at the General Post Office. Some experiments were made by means of two large copper parabolic reflectors placed at varying distances. At ½ mile distance we obtained fairly good signals. The receiving apparatus used was of the coherer type. We gradually extended our experiments up to a mile and three-quarters, but the signals commenced to fall off in power very materially. While the experiments were going on, I happened to place my ear close to the receiver, and I noticed then that the sound of the sparks which were passing at the transmitter became perfectly distinct, and I have some suspicion now that the signals received were not entirely due to electrical impulse, but were also caused by sound vibrations transmitted through the air. As regards the experiments generally, I had, unfortunately, selected perhaps the worst kind of country over which to obtain good results. The whole of Salisbury Plain is of an extremely dry and chalky nature, and it is impossible to obtain a really good earth; even with lofty aerials suspended from balloons the signals obtained were feeble and uncertain. The scene of operations was next transferred to Fort Burgoyne, near Dover Castle. We found, however, that it was practically impossible to transmit messages more than a distance of about a mile and a half. In that case also I had selected most unsuitable ground, as the whole locality is a mass of chalk, and it was perfectly hopeless to get a really good earth. It was immediately after this that Mr. Marconi made his classical experiments between Dover and Wirnereux, a distance of 70 miles, and from that day the success of the apparatus was assured. It is marvellous to Mr. Kempe.

Mr. Kempe. note the extraordinary strides made in the whole subject since it was first initiated; it is an indication of how necessary it is to study a subject as a specialist and to keep right up to date with the advance of science, otherwise it is simply hopeless to keep up with the information on the subject. I think this point applies not only to wireless telegraphy but to every other branch of science.

Mr. Morris-Airey. Mr. H. MORRIS-AIREY: The paper not only brings out many points of the utmost practical importance, but it is also full of suggestive material of pure scientific value. The question of interferences between an undamped wave system and a spark system is one we have had ample opportunity for testing here at the College. We are only 8 miles from Cullercoats, where a 3-k.w. Poulsen arc is often in use, and we find that it is only when we tune-in very carefully for their known wave-length that we can detect that the arc is working. The latter part of Mr. Taylor's paper referring to his study of atmospherics is of particular interest to me. Together with Dr. Eccles, I spent a considerable time on this subject last summer. The period selected was the season when the atmospherics are strongest, and the observations, partly in the morning and partly at midnight, extended over three months. We did not simply count the actual number of atmospherics in a given interval of time, but we aimed at studying the individual atmospherics. We recorded on paper as nearly as possible the exact instant at which the atmospherics occurred, and also recorded the intensity and character. The pencil marks showed roughly whether the atmospherics were sharp clicks, rumbling, grinding, or hissing sounds as heard in the telephone receiver. We were able to get exact correlation of our records by making use of the signals sent out from the stations at Norddeich and the Eiffel Tower, and the night messages sent out to the Atlantic boats from Poldhu. Any differences in our watches could be corrected by this means. Over 70 per cent. of the recorded atmospherics corresponded, not only in time, but also in character; thus if a long rumble or sharp click was heard at the one station a similar sound was recorded at the other. The recording stations were situated in the London and Newcastle districts, and were thus separated by about 270 miles. The conclusions drawn from these experiments were that most of the atmospherics have their origin at a great distance from both stations, and few of the observed atmospherics were likely to be caused by local weather conditions. It may be that their origin is in electrical discharges taking place in the upper and rarer parts of the earth's atmosphere. Their origin may be connected with that of some types of magnetic disturbance and probably will be finally traced to the arrival in the earth's atmosphere, of negatively charged electrons from outer space. I think that when the origin of these atmospherics is solved there will be found to be a close relation between them and magnetic variations and sun-spot phenomena. On one point my observations differ from Mr. Taylor's, namely, with regard to the tuning of atmospherics I find that listening on a wave-length of, say, 1,000 metres, we get a set of atmospherics which differ

largely from what is observed on a shorter wave-length such as 600 metres. Some preliminary experiments have been made on this point with the antenna duplexed on wave-lengths of 2,000 metres and 600 metres. The observations tend to show that a large number of the atmospherics are tuned. The point raised by Mr. Taylor with regard to the variation of the dielectric in the neighbourhood of the antenna, causing signals from a distant station to swell and fall in intensity; I have frequently observed this in the messages sent out from Poldhu at 1 a.m., but was not sure whether it was due to actual variation in the power. I would like to ask Mr. Taylor whether he has made any observations of the frequency of these disturbances in connection with general meteorological conditions. It would be interesting to see whether these disturbances would be noticed under conditions such as a high cirrus sky, which is usually associated with extensive regions of homogeneous atmosphere. Mr. Morris-Airey.

Mr. T. R. Johnson: Mr. Taylor points out on page 121 that it is very desirable to take telegraph wires into wireless stations by means of underground cable. Well, no doubt Mr. Sörensen could speak better on the point of view of disturbance to the wireless system, but three years ago it was impressed on us that it was equally desirable from the telephone point of view. The wireless station at Cullercoats is connected with the Post Office Telephone Exchange at Whitley Bay and the wires were at first entirely open. On the same line were a number of wires running to various subscribers' premises. The last two spans of wire to the Cullercoats station were within the area of the station, the last span being under the aerial. We not only got false calls on that circuit but on the neighbouring circuits also. We got flashes at the Post Office Exchange at Whitley Bay, and the heat coils were actuated on several occasions. The last two spans of wire were then replaced by rubber-covered cable, but the result seemed to be just the same as before. The heat coils were again actuated on one or two occasions, and the flashing continued to the great disturbance of the operators. We then substituted for the rubber-covered cable a lead-covered cable and terminated that cable just outside the wireless station, but continued it into the building by means of an unsheathed cable. A marked improvement took place, but a complete cure was not obtained until the circuit into the station was completed by means of lead-sheathed cable close up to the telephone apparatus. To any one who has listened on a shore station, there can be no doubt that there is a great deal of "jamming," and I cannot help thinking that the suggestions put forward by Mr. Taylor will go a long way towards eliminating these troubles. Mr. Johnson.

Mr. B. A. Robinson: We get rid of some of the atmospherics at Cullercoats by simply putting the antenna to earth, when the number goes down by at least 50 per cent. Some of the atmospherics are tuned and some are not. Mr. Robinson.

Mr. J. M. Robb: I can appreciate the interferences described by Mr. Taylor for the reason that in the Post Office we are very familiar Mr. Robb

Mr. Robb. with inductive troubles due to pre-charged aerials in the shape of telegraph wires, the effects of which on telephones are not unlike those suffered in wireless telegraphy. For instance, where we have a fast-speed telegraph wire attached to a long submarine cable, disturbances and interferences with adjoining telephone circuits are very pronounced and require a very high degree of maintenance in order to shut these out as far as might be practicable. I should like to ask whether Mr. Taylor is convinced that the screening of telephone and telegraph wires referred to immediately in the field of the wireless station is sufficient to eliminate interferences with these wires. Further, all telephone and telegraph wires are fitted with lightning arresters, and these are, of course, so designed as to afford the most efficient discharge. We occasionally have failures on these lightning protectors, as, of course, we expect to have, but we get failures occasionally even when there is no lightning about. The cause of these has never been explained except that the man who finds them may say that they are due to dust. I would like to ask if there is any chance of connecting these failures with interference by wireless, because if so the number of failures to which we assign any cause will immediately drop.

Mr. Whillis. Mr. G. WHILLIS: I must say that it is surprising to many so closely associated with wireless telegraph work to find that so much chance of interferences can be eliminated. It is hopeless for us to expect a discovery of some method of shutting out all interferences.

Mr. Drummond. Mr. A. L. E. DRUMMOND: Mr. Kempe in his remark has cleared the ground of many of the questions which I was going to ask. Atmospherics are analogous to faults largely met with in telephone circuits using an earth return. I have had a good deal of trouble in that respect, and I am reminded of the time when we used earth returns prior to the introduction of the metallic returns. We were greatly troubled with interferences due to stray tramway currents which caused the indicators to fall and false calls to be given.

Mr. Paterson Mr. T. PATTERSON: Many years ago I was associated in a small way with Mr. Taylor in erecting one of the first wireless stations in Great Britain. The system installed was the now antiquated one of induction between parallel lines on the Island of Rathlin and the main land of the County Antrim opposite, but it served its day very well. In those early days atmospherics were just as troublesome as at present, and it was proved that land lines, earth- or sea-connected at each end and of low chronic resistance, are affected equally with Hertzian-wave installations. The land line on the main land was a veritable, and very noisy, barometer; it presaged atmospheric disturbances. In my attempt to ascertain the cause of these noises it was observed that a weak current existed in the line, which varied in strength from zero to 3 milliamperes, and in direction with each turn of the tide. The wire was terminated in the sea at each end.

Mr. Vernier. Mr. CHARLES VERNIER: The first thing that occurs to me is the very great number of difficulties which wireless operators experience,

and in face of the many sources of interferences detailed in the paper, it is surprising how they are able to get along at all. It seems to me that the Poulsen system must have many advantages over the system used by Mr. Taylor; it seems that it would be less likely to cause interference in the way that the spark system appears to do. Mr. Johnson spoke of the use of lead-covered cables in connection with the telephone lines leading to wireless stations, and although the author on page 121 only says that lead-sheathed wire may be used, I think Mr. Johnson's experience shows that such cable should always be used. I should like to ask Mr. Taylor at about what maximum range can electrostatic interference cause trouble in operation. The subject of atmospherics seems a rather mysterious one. Mr. Morris-Airey and the author do not seem in agreement as to their source, as the former attributes them to the same cause as magnetic storms, whereas the author tells us that at such times they are less marked than usual. I suggest that these atmospherics may be due to lightning storms in the tropics, which would be sufficiently distant to affect stations in these islands at the same time. The author has not referred to the influence of daylight, or the efficiency of transmission. I understand there are two theories in explanation of this: One is that the aerial becomes discharged by the ultra-violet rays during the period in which it is electrified negatively, while the other is that the waves dissipate themselves in space owing to a similar influence. I should like to ask the author whether recent progress has shown one theory to be more correct than the other. With regard to the detectors used, I should also like the author to give us the relative sensitiveness of the Marconi magnetic detector as compared with the electrolytic and crystal types of detectors. **Mr. Vernier.**

Mr. J. E. TAYLOR (*communicated reply*): Commander Loring has given some very interesting information regarding the more or less indiscriminate wave-lengths used by ships, and refers to possibilities of minimising interference by perfection of installations and proper use of apparatus by operators. In these respects I entirely agree that considerable improvement is possible; but I fear that in the matter of suiting the strength of radiation to the range of communication in hand no satisfactory solution involving a change of power at the transmitter will be forthcoming. In the matter of unifying and standardising the apparatus used on ships the very considerable total cost involved is a formidable obstacle to anything but gradual changes being made. His remarks on atmospheric electrical disturbances appear to confirm my own observations in general. I am still in doubt, however, whether there is sufficient evidence to show that the increased trouble from X's found when using very long-wave aerials is other than a natural consequence of the larger area of conductor exposed as compared with short-wave aerials. Musical note transmitters, doubtless, afford some assistance in penetration through bad atmospheric disturbances, provided they are of an aggressive tone; but I am inclined to think that the importance of the musical note for this use is usually **Mr. Taylor.**

Mr. Taylor. somewhat exaggerated. In my experience the right kind of scratching signal will be read almost as easily as any musical note. With regard to the remarkable effects connected with long-distance "freak" communications, the point referred to by Commander Loring that a station may lose touch with a ship whilst a much more distant one will still remain in communication, I think a possible explanation may be that local areas which may sometimes enclose a station may be more or less blotted out, from a wireless point of view, by atmospheric ionisation existing in patches or banks. With reference to Sir Oliver Lodge's remarks, what I conceive to be the most vital part has reference to the selectivity of the Lodge-Muirhead system using upper and lower capacity areas. Whilst I fully admit the force of the arguments used, and accept the statements made regarding the extent to which one Lodge-Muirhead station can be made independent of another neighbouring station, using a wave which differs sufficiently, I have yet to learn that the Lodge-Muirhead can do better in this respect than coupled systems using earth. It would be extremely interesting to put the matter to a practical test in a systematic manner. For this purpose I would suggest dual stations at each of three or four places. Each dual station should be capable of using at will either the Lodge-Muirhead or the coupled earthed system as alternatives to one another. At the back of my mind I confess to an impression that Sir Oliver is unduly decrying the syntonic qualities of earthed systems. Mr. W. Duddell has raised the question of operating with more power and larger working margins. Probably he has looked at this matter in all its bearings. Before I can agree, however, to the practicability of the course he recommends I would wish to be satisfied on two or three important points. First, as to the cost of construction and maintenance of stations for ranges of working equal to those obtained at present by the use of such simple and inexpensive stations as are energised by a spark coil and battery. I think it would be a distinct hardship if the use of such installations were debarred by legislation. To operate effectively with ten times the power would not only mean a costly transmitter, but also a costly aerial construction if the power is to be usefully radiated. In the second place, I am not at all clear that installations of sufficient magnitude could be carried on the average passenger ship. Further, the range of ship and shore installations has not much room to expand itself, even under present practice, because the wave-length is limited to 600 metres, and it is impracticable to construct an aerial suited to a 600-metre wave which will take up unlimited energy for a fixed sparking rate. Indeed that limit already makes itself felt on comparatively low-power installations. The electric tension which the aerial can attain is limited by the formation of brush discharges. This factor will therefore limit the power per spark which can be usefully applied. The degree to which receivers can integrate the received energy from a succession of sparks is also strictly limited. I am therefore inclined to the view that Mr. Duddell's proposal would result in serious curtailment of the range, and therefore of the utility of wireless telegraphy

for ship to shore purposes. Nor, I imagine, would the illustrative figure of ten times the normal power which he cites greatly alter the complexion of the case as regards many forms of disturbance in working. Some much more drastic increase in the strength of signals would, I think, be necessary in order completely to eliminate trouble from an average summer-time storm of atmospheric disturbances. Mr. Taylor.

With regard to interference from precharged aerials, I am thoroughly in agreement both with Sir Oliver Lodge and Mr. Duddell that the interference produced at a distance by this type of aerial cannot be due to electrostatic induction. I thought I had made this clear in the paper. But I still see no reason why at short distances, say $\frac{1}{100}$ or $\frac{1}{50}$ of the range of the station, such an effect should not be felt. The explanation which I have suggested to account for the interference at a distance is that the precharged aerial, as usually operated, gives out an impure wave.

Dr. Erskine-Murray's remarks on the sharpness of tuning of signals from quenched spark transmitters at distances have been confirmed by Post Office experience. It has also been confirmed that the sharpness of tuning depends to a considerable extent on limitation of radiation from the transmitter. By introducing sufficient inductance into the transmitting aerial it is possible to make the tuning extremely sharp. As in most other systems, the matter resolves itself into a compromise between sharpness of tuning and loss of range of communication. In regard to the proffered explanation of X's as due to tropical thunderstorms, I would only mention that these disturbances often appear to be practically absent at times when abnormal ranges of communication are possible. I do not know that I can add anything further in explanation of the mutual disturbance coefficient. I have endeavoured to show that a mathematical expression to be suitable for this purpose would be an extremely complex one. It would also be very difficult to formulate in view of the nature and variety of factors involved.

Mr. Sorensen speaks for the immunity of interference obtained when using the Poulsen system of continuous waves. I think it must be generally conceded that at distances of more than a few miles a very high degree of immunity can be secured. My point was rather in reference to interference at close quarters which might theoretically be assumed to be non-existent. I think, however, I am right in saying that experiment shows that interference between arc and spark systems does exist at short ranges and that it is by no means a negligible quantity.

In reply to Dr. Stroud, I may say that while it is true that musical spark transmitters produce a tone in the telephones of the receivers which can often be read over interferences, this can hardly be said to be peculiar to such transmitters. A penetrating, scratchy sound can be read with equal facility.

Mr. Kempe calls to my mind some of the very earliest exploits in wireless telegraphy, which serve to emphasise the great advances that have been made in the subject since the date to which he refers. I

Mr. Taylor. was associated with Mr. Kempe in most of the experiments made at that time, and in these the old-fashioned coherer was invariably used for receiving. This instrument frequently introduced vagaries of its own, and if, on top of these, other interferences were superposed, it is not difficult to imagine that the signals would become totally undecipherable. With the auditive receivers now used, the exact character of the transmitted signals is so faithfully reproduced that it is generally possible to read messages through considerable interference.

The remarks of Mr. Morris-Airey concerning observations on atmospheric disturbances are of extreme interest, and I am very glad to know that the subject has been taken up so thoroughly. In general, there appears to be fair agreement between the results in which he is concerned and those referred to in the paper. I had already planned out a series of tests with diplex receiving apparatus to test whether any marked difference in the character of atmospheric disturbances on receivers tuned to widely different wave-lengths existed, but have been prevented by various circumstances from putting the plan into execution. I hope, however, to confirm the observations of Mr. Morris-Airey on this point on an aerial far removed from town disturbances and possible secondary effects. In connection with the subject of atmospheric electrical perturbations, it has been usual to record the state of the weather at the time of taking observations, but I have not been able to trace any connection other than during thundery weather.

In answer to Mr. Robb as to the effectiveness of screening telegraph wires only in the vicinity of a wireless aerial, my experience is that this course is entirely sufficient. I have not heard of any cases where interference with telegraph or telephone circuits has occurred except the circuits themselves or other circuits running alongside come within a very short distance of the wireless station.

The question has been raised by Mr. Vernier as to whether atmospheric disturbances may not be due to tropical thunderstorms. I think that whilst effects from these storms may possibly make themselves felt even in these latitudes, they cannot be a prime cause, because of the distinctly periodic character of the normal disturbances, especially the diurnal maxima periods. To eliminate perturbations of wireless receivers due to telegraph apparatus and sparking at relay contacts, screening by enclosure in metal cases can only be made entirely effective if the whole of the telegraph instruments and wiring be completely encased. A screen over any one portion of the apparatus is not sufficient. With reference to the day and night variations of range of signalling, I hold that the most likely cause of this phenomenon is ionisation of the atmosphere by sunlight, possibly for the most part in the upper regions. This explanation was offered by me in a paper published in 1903 on "Characteristics of Earth-current Disturbances and their Origin." *

* *Proceedings of the Royal Society*, vol. 71, p. 225, 1903.

MODERN LONG-DISTANCE TRANSMISSION OF ELECTRICAL ENERGY.*

By W. T. TAYLOR, Member.

Mr. W. T. TAYLOR (*communicated reply*) : The confidence expressed by Professor Jackson (President of the A.I.E.E.) in the ability of engineers to make the necessary discoveries and inventions to carry power transmission to a much wider limit than it has yet reached, is in perfect harmony with my own views. I do not hesitate to predict that during the next ten years transmission lines will be operated at above 200,000 volts, but as to the ultimate voltage for practical operation of our lines I am unable to express an opinion. In reply to Mr. Welbourn, I think that at the voltages dealt with in the paper it is commercially impossible to transmit large amounts of power by means of underground cables for distances of 200 miles or more. The reasons for not dealing with the subject of direct-current long-distance transmission are : (1) personal experience with this branch of engineering is limited to notes taken while on a visit through France ; (2) the subject of this paper is only based on a broad practical experience in connection with a large number of the greatest transmission systems in the world, and quite large enough to be treated in one paper ; (3) the various schemes mentioned for the operation of 3-phase lines, etc., might be applied in a modified form to the operation of direct-current long-distance lines. Mr. Welbourn and other speakers state that the life of wooden poles is about 30 to 35 years. This happy condition may apply to Great Britain, but the timber used there is not used to any extent elsewhere, and the character of ground, etc., is different, as is the treatment of poles. The average life mentioned is generally correct where transmission lines have been built and are now operating, and the estimate given would be nearer the actual figure at 11 years instead of 12. Since writing the paper I have had an opportunity of looking into the life of transmission poles in Brazil. While on a tour of inspection, just completed, into the interior of that country in connection with a compilation of general hydro-electric data of the most important systems in operation, I was shown a native tree, and poles from that class of timber, which is considered by the Brazilians to have a longer life than any of the figures given in the discussion. Some of the operating companies say its life is about ten years longer than that of an iron pole. As an example, one of the poles was bared

* The paper and the report of the discussion will be found in Vol. 46, page 510.

for about 18 in. below the surface of the ground, and on careful examination of the parts below the surface no deterioration could be detected, although the pole in question had been in the ground for over 12 years without treatment of any kind. As is well known, the chemical formation of soils in different parts of the world, and very often in one small locality, vary; thus if a pole will last 20 years in one place it does not follow that the same kind of pole will have the same life in another ground. Mr. Welbourn deals with the length of spans, and in a way compares them with spans in other countries. The correct length of spans varies with a given tower or pole, and a given size of conductors and their number, with a further allowance for strong winds and snow, and perhaps also with the courage and experience of the engineer. The transmission company with which I am engaged at the present time has 60,000-volt lines crossing the Strait of Santos-Guarujá. The total length of the crossing is about 2,000 ft., and the height of each tower is 275 ft. The steel cable conductors are anchored on both sides of the Strait to specially constructed insulator supports, the whole being quite unique in character so far as the methods of anchoring and insulating are concerned. All the large steamers from Europe, America, and other parts of the world must pass underneath this 60,000-volt transmission line before entering the harbour or docks. The transmission line on the Santos side of the Strait is tapped by a copper conductor which leads off to a sub-station designed for an ultimate capacity of 20,000 k.w. This is only one of a great number of transmission line spans now existing in various parts of the world. As another example, I was employed on a long-distance transmission system in Central America which has spans over 750 ft., using no larger conductor than 0·0259 in. diameter S.W.G. hard-drawn solid copper wire; two such spans are used in a distance of 50 miles, the remainder of the spans being approximotely 450 ft. apart. Among those not familiar with the practical operation of long-distance transmission lines there exists some diversity of opinion as to the usefulness of the overhead grounded cable for lightning protection, particularly among those who have not had experience with this method of operation. I have fortunately had exceptional opportunities of studying the behaviour of lightning on long lines operating in various parts of the world. In 1898 I was engaged with a hydraulic power company in South Africa using the same system of protection, and we had every reason to believe that it was effective. This method of protection is used by a large number of the most able transmission companies on the American Continent and found to answer well. I have never yet heard of a case of the falling of an overhead ground wire. Where steel towers are used, and therefore long spans, the question of aluminium wire or cable for transmission line purposes is still somewhat in doubt. Where wooden poles are used, and therefore shorter spans, the use of aluminium cable or wire is permissible, and has already proved extremely successful. No matter what improved methods of manufacture may be discovered with aluminium,

it will be practically impossible to get rid of line troubles on long spans over open sections of country and in snow-clad regions. For the same cross-section copper wire collects a little more snow than aluminium. This has been noticed on long-distance telephone lines in California, where copper and aluminium lines exist in the same locality.

Mr. Vernier has given some comparison of the cost of steel towers and wooden poles. His figures are not, however, based on actual experience, and the assumption can only be classed as absolutely local to Great Britain. In addition to the information given by Mr. Vernier, I am able to give a practical working example of a long-distance transmission steel tower line on which I have lately been engaged in Mexico. This steel tower line has been in regular operation for the last six months, and is, to my knowledge, the cheapest steel tower transmission line in the world.

Physical Data.

Thickness of material ...	All material above ground, $\frac{1}{8}$ in. All material below ground, $\frac{3}{16}$ „ Feet of towers ... ... $\frac{1}{4}$ „

Weight of each tower, 1,850 lbs. (All the towers are of the same height and weight, including the dead-end towers.)

Height of towers	From the lowest cross-arm to the ground surface ... 38 ft. Total height above the ground ... ... 49 „ Total height of towers (over-all height) ... ... 55 „
Erection data	Maximum number of towers set per day, per gang ... 22 Average number of towers set per day, per gang ... 15

Order of work :—

1. Surveying	The most important points to bear in mind are—keep low; keep on good ground; make sufficient right-of-way clearance.
2. Hole digging	If possible get local help by contract per tower—make a templet of the foot of the tower.
3. Tower assembling ...	Assemble all towers on the field—examine the galvanising carefully.
4. Tower raising	Use block and tackle where possible—number all towers after they have been raised and thoroughly bolted down.

5. Insulators	Hoist and set in the usual way—a most important point is to minimise breakage or chipping of insulators during transit on the field.
6. Wire stringing	Transport the reels to a convenient place; use men for short lengths, and horses or mules along with men for long lengths—pull-up and tie-in at intervals at the same time—tie-in solid at the point of dead-end.
7. Inspection	A "line-rider" or experienced transmission lines-man must ride along the finished line taking notes of any defects in the erection of towers, insulators, and conductors; also allowances given for sag on extra long spans; careful watch should be made for kinks, etc., in both conductors and overhead ground wire.
Cost of towers per mile ...	The cost of towers at factory was £13 5s. each. The cost per mile of tower line, including all labour, freight, or transport, erection, and inspection of the two circuits of 3-phase line, £480. Average spacing of towers, 450 ft. Length of transmission line, 87 miles.
Electrical data	Two 3-phase circuits of No. 3 hard-drawn B and S copper conductor.

Spacing of conductors	...	5 ft. 2 in.
Resistance (R)	...	84·5 ohms.
Inductance (X)	...	61·5 „
Impedance (Z)	...	104·5 „

The spacing for $\frac{2}{3}$ distance ...	...	5 ft.
The spacing for $\frac{1}{2}$ distance ...	...	10 „
Therefore: Resistance (R) ...	...	84·5 ohms.
Inductance (X) ...	...	65·3 „
Impedance (Z) ...	...	107·0 „

In putting up wooden pole lines the best native tree available to meet existing financial conditions should be used. Various questions have been asked about the protection of lines from local faults, that is, short circuits, "grounds," and the like. I should be glad to receive any suggestion from members bearing upon the protection of lines 200 miles from the nearest generating station, as ideas and discussions on this subject might lead to other important discoveries and inventions. The cheapest built and least protected transmission lines in the world are operating in California (not including any of the plants put into operation during the last few years). On some power plants switch relays have been designed to operate at too low a current, they have therefore been "tied down." Other plants have found it necessary to lock their relays or disconnect them entirely on certain transmission lines where frequent interruptions occur. Other long-distance transmission companies set their relays at from 50 to 150 per cent. above the maximum operating current of the line. Up to recent years the majority of long-distance transmission companies in California did not operate with any other protection than the ordinary fuse-wire, and every company, strange to say, had a particularly good word to say about this so-called method of protection.

The Merz-Price system may be all right for city networks, but cannot be applied in its present form to long-distance lines. The wiring diagrams asked for by Mr. P. V. Hunter are given complete in Figs. 8, 9, and 10, and show all that is necessary for an engineer to plan the lay-out of apparatus, equipment, etc., as well as to take charge of all necessary switching-in and out of lines and transformers and their transfer to busbar sections, etc., after a few minutes' study. This also applies to the wiring diagrams of the generating stations, which, contrary to some of the statements made, are quite simple. The idea of protecting a transformer or generator from another, or busbar sections from each other, appears to be strange and entirely crude, but in my opinion it is the only method worth any dependence where large units are used. Having kept in touch with most of the extra high-tension systems operating in Great Britain, I had an object in placing this paper before the Institution, which, as far as the discussion indicates, has proved satisfactory. The greater part of what has been said has taken the form of questions, and has not given what was really wanted, *i.e.*, methods of operation, practical examples of cost, methods of protecting long lines, and diagrams of generating and sub-station lay-out, etc., in Great Britain.

Mr. Redman states that it is only possible to receive a higher voltage at the receiving end of a long underground cable. My experience of one plant in particular (the Guanajuato Power and Electric Company) does not agree with this statement. Some years ago, when engaged with this company, which has a sub-station located over 100 miles from the generating station, our lightning arresters would either flash-over or make attempts to do so whenever the load dropped below a readable value on the instruments at the sub-station. This particularly

demonstrated itself when running with open switches and transformers cut out at the receiving end. Further, during the time I was engaged with the California General Electric Company, we made it a practice, simply on account of this, never to start up without an induction load at the receiving end of our lines because of the increase in voltage at the generating end. The diagram given on Fig. 1 is not an actual regulation diagram, but simply represents a sketch of that which was used in the early days by transmission engineers, and is still used by many in a slightly modified form. Probably the reason why a great many of the papers before this Institution are of the "parish pump" description, as cited by Mr. Trotter, is because of the way these engineers view a given subject. They permit themselves to circle round a given set of ideas quite out of date, and feel ever ready to condemn anything which turns their ideas and practice from their particular course. The main reason why our American cousins have soared ahead in a short space of time, is because of their aptitude to drop a good thing for something better. As in everything else, one is apt to be mistaken, but the experience has been gained with better results next time. I firmly believe that the time is not far distant when Great Britain will have both 40,000-volt direct-current and alternating-current long-distance transmission lines, and the maximum voltage not less than 100,000 volts. This statement may appear radical, but no more so than some things appeared when first mentioned as being possible in Germany and other parts of the world. The stringent restrictions of the Board of Trade may affect many of the future long-distance transmission schemes that must necessarily spring up in Great Britain. I agree with Messrs. Matthews and Wilkinson's statement that 200,000-volt is now considered to be within the range of practicability. With higher voltages the difficulties increase, and also danger to life and property.

Mr. Cramp asks if the formula on page 513 for the coefficient of self-induction has been used for obtaining the reactance given on page 541. The exact formula given has not been used, but one very near it has been employed. The quantity b is in its broad sense expressed as—

$$b = \frac{x}{z_a} = \frac{x}{(R - j\,x)^2},$$

and f is used as representing the frequency of a given system; also t refers to the various reactance-factors in different parts of the system. The reason for not carrying out the calculations as outlined by Mr. Cramp, and partly shown on page 514, is because the method is an old one, and there now exist several technical works giving these constants in tabulated form. If I have correctly understood the meaning of Mr. Flemings' words regarding the feasibility of grounding one of the three line conductors, his method would not be a success, first, because with a delta-connected line at all ends one ground would constitute a short circuit; secondly, because the electrostatic conditions might rouse all the neighbouring telephones and telephone companies, and local light and power companies operating series alternating-current arc systems; the

unbalanced conditions would get worse as the load came on the line, both for the power company using this method, and any neighbouring company operating overhead lines. Also the extra electrical strain placed on the line insulators and apparatus at both ends of a long line would reach a critical point. The method referred to has been used in California for a number of years on a delta-connected system, but is only applicable to short transmission lines at moderately high pressures, and where either water power or cheap coal is available. Thirdly, the purpose of the ground wire would be frustrated if it were not placed above one circuit, and on either side and above for two circuits of a line. Fourthly, being of copper, or more probably of aluminium, the possibility of reducing the weight and cost of towers, and assisting in their support, would also be reduced. The electrical disturbance of a system caused by the flash-over of lightning arresters is not meant to refer to a sudden interruption of a loaded transmission line, although this could happen, and does happen, on systems using the multiplex type and the horn-gap type of arresters. The paper precisely referred to a discharge from direct lightning over the two types of arresters above mentioned. Mr. Faye-Hansen is quite right about the lettering of Fig. 1 being exchanged. The statement referring to the use of three 6,000-k.w. transformers with a 12,500-k.w. generator sounds out of place, but actually it is not so. The station busbars are so sectionalised that seven sets of twenty-one transformers can operate in multiple or No. 1 generator be operated with No. 7 bank of transformers, or *vice versâ*, so that in actual service and with this character of generating station lay-out there is little difference whether the transformers be three 1,000 or three 10,000-k.w. so long as there is generator kilowatt capacity to correspond. However, I should recommend the same kilowatt capacity of transformers and generators for a given section. These tables quoted are not based in any way on the theoretical formula given on pages 513 and 5, they are based on tests and can be relied upon for all practical calculations. Fig. A will give Mr. Faye-Hansen the cross-section of the suspension type insulators—this drawing may also be of interest to many of the members. Another question mentioned by the same speaker is with reference to line and transformer connections. Under this heading all the electrical connections refer to the transmission side of the transformers. It is quite possible to operate any transmission line with a star connection (non-grounded).* It is bad policy to make a ground through a resistance on the high-voltage side or line side of the transformers, as the neutral point must shift and the factor $\frac{1}{\sqrt{3}}$ cannot hold good. It is a decided advantage to operate a new plant in delta on the high-voltage side when the load is comparatively small, and the transmission of some length, provided the energy loss and regulation come within a given limit; there are few systems built which have a comfortably loaded line and a maximum operating voltage

* "Stationary Transformers," by William T. Taylor, McGraw Publishing Company, New York.

within less time than five years. Engineers of to-day look somewhat beyond that period of development, and build for a future of from ten to twenty-five years.

I regret I am not able at the present time to help Mr. Malpas with additional information regarding the dimensions of towers corresponding to tests mentioned on page 528, as all his data are not at present available. He wished to impart the same meaning as Mr. Lustgarten ably defined it, viz., "A flat plain disc has a greater electrostatic capacity than a similar disc with concentric petticoats on the under surface. . . ." With increase of voltage the effect from corona is parallel with the concentric petticoats. The barbed wire mentioned by Mr. Mallinson might be all right for short spans where wooden

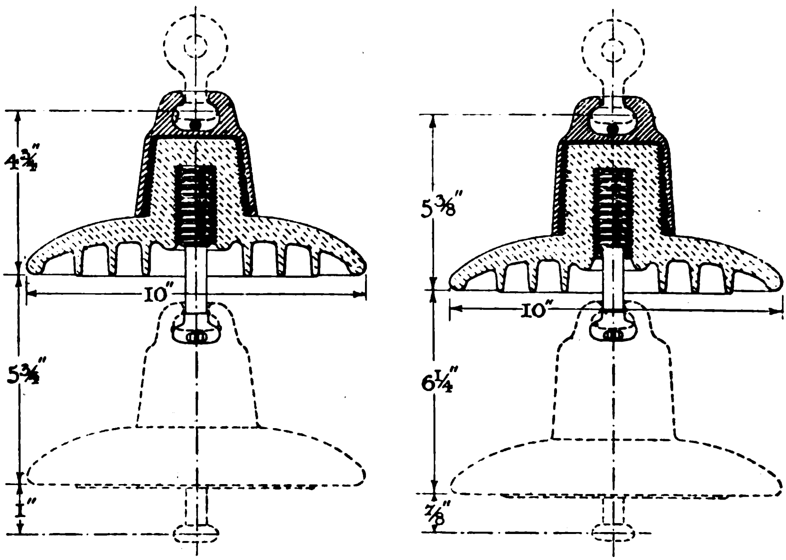


FIG. A.

poles are used, but would not do for long spans. The size of steel cable used on steel tower transmission lines up to the present time varies from $\frac{3}{16}$ to $\frac{5}{16}$ in. diameter. I have experienced the climatic conditions affecting surface leakage mentioned by Mr. Mallinson, and on two very long transmission systems the insulators had to be enlarged on certain sections which experienced frequent interruptions, after which change no further trouble occurred. These interruptions were usually in the form of flash-over of insulators, and generally occurred in the early morning just after sunrise. The theory evolved was that it was due to condensation effect. The suspension type of insulator shown in Figs. 18 and 19 has not been designed for use as a

horizontally arranged dead-end insulator. It may be used as such for generating and sub-station wiring, but even for this it is not recommended. Within my knowledge there does not exist to-day in any tropical country a 100,000-volt transmission line of the type of construction shown in Fig. 30. This is worth remembering when about to build such a line in a country where rainy seasons are very severe. Wooden pins are no longer used for voltages above 33,000. On the older transmission lines they all have been practically replaced, principally by cemented-in galvanised iron pins of the pipe or tube form. I have not seen the Great Western Power Company's installation mentioned by Professor Marchant, as I left California before work was commenced on the preliminary development, but I believe that had the engineers the same thing to do over again they would leave out many of the transpositions and all expense involved in transposing the power conductors. Since this company decided upon the number of transpositions given, other similar companies dared to omit transpositions of any kind on their power lines. The general tendency at the present time is to decrease the number of transpositions per given length, this being the result of investigation and of actual experience. The effect of hydraulic relief valves cited by Professor Marchant is a valuable element to safe operation of plants of any magnitude. I have witnessed the operation of relief valves working under effective heads as high as 1,500 ft. and coupled to a unit as large as a 8,500 H.P., when the noise could be heard at fully 2 miles' distance. We are anxiously waiting for an electrical relief valve that will perform the same function as the hydraulic relief valve, *i.e.*, bring the system to normal condition again without the help of human power. For such loads as 15,000 to 25,000 k.w. mentioned by Mr. Sparks, not less than two circuits would be used, so that with one down the other can be placed in service. Where two circuits are used it is customary to operate both of them in parallel and to arrange the sectionalising and cross-over switches (with or without primary relays) at points along the line where the line-riders are located—telephones being installed in each of these patrol houses. The primary relays mentioned here may be set to operate at not less than 150 per cent. of the full-load current or maximum current the line has ever taken, otherwise they would constantly be tripping out on partial "shorts." By the use of these relays it is possible to locate the faulty section immediately and change over the line without first notifying any other person than the generating station operator, after which the matter may be talked about at leisure. On very large systems automatic oil switches, such as mentioned on pages 521 and 522, might be used to great advantage by the patrol men; in fact, the system shown in Fig. 11 (System of Connections—Central Mexico Light and Power Company) used in a form to suit local conditions, and with primary relays, is the best and only transmission line protection in use at the present day for lines over 100 miles long. There are so many factors that cover the question asked by Mr. Sparks *re* "continuity

of service" that one would have to go right back to the design of the line under consideration, and follow it up in detail until the manager or chief engineer himself might be the biggest factor (or whatever one might call him) hindering the continuity or service.

I do not feel quite so sure about the general use of direct-current at high voltages being as far off as it was five years ago. We have practically discovered the ultimate commercial operating voltage for alternating-current circuits, and know that there exists a loss by the result of corona which may offset, from an operating and maintenance point of view, the saving by the use of direct-current transmission. If closer study were given to direct-current long-distance transmission systems by some of our able transmission engineers we might hear of further discoveries and inventions; in fact, it goes without saying, that had equal brains been given to this branch of our work, high-voltage direct-current transmission would have been further advanced than it is to-day. As each tower is grounded either by direct setting into the earth or on to cement blocks, no further discharge to ground is thought necessary, but this might be done in the case of towers set on to cement blocks if a difference of potential is measurable. In some cases, dependent upon the soil, it is advisable to extend the feet of towers beyond the cement block into the ground below. With long spans and heavy conductors such as are now used on many of our high-voltage transmission systems it is good practice not to clamp the conductor down tightly at the insulator, as the intermediate and flexible towers are not usually designed to take care of the severe strain arising from one or more of the conductors breaking. The difficulty, so far as my experience goes, is in the design of clamp, which might kink the conductor (after it had slid through the clamp a few feet) at a point from 400 to 750 ft. from the end of the break. Various forms of clamps have been designed, but so far as I am aware there is none yet that will permit the conductor to slide through without damage to some portion of it. The clamp shown in Fig. 18 is one of the best forms; that used on the Central Mexico Light and Power Company's transmission lines is made in the form of an ordinary trolley-car. The various questions of Mr. Peck have mainly been replied to, except that referring to the operation of two transformers connected, delta-star. If the neutral points of the transformer windings connected to each end of the line are grounded, this is true only under certain conditions of load and length of line, etc. Some power companies have operated their lines and given service to large power consumers during the time one of their transmission conductors have been broken down by using the same method of connections, *i.e.*, delta-star raising with star-delta lowering.

Mr. Peck is quite right about going up to the limit of insulators at the very beginning if they have been designed for delta voltage, but the majority of companies put in insulators at the commencement for the star voltage. There is one matter of interest to all operating engineers or "system engineers," as one speaker prefers to call them, namely,

the possibility of operating a 3-phase system and delivering 3-phase currents with only two transformers and two conductors, or two transformers and three conductors. Practical "system engineers" when short of apparatus, etc., are always on the look-out for some scheme of connections that will give them the required phase relations and kilowatt capacity to tide over a serious breakdown. The following two diagrams, Figs. B and C, may be of interest and helpful to some of the members. A full explanation of connections of this kind is always welcomed by "system engineers." Practical engineers operating plants have very little time at their disposal when a breakdown occurs, and the possibility of keeping things going with schemes of this kind is

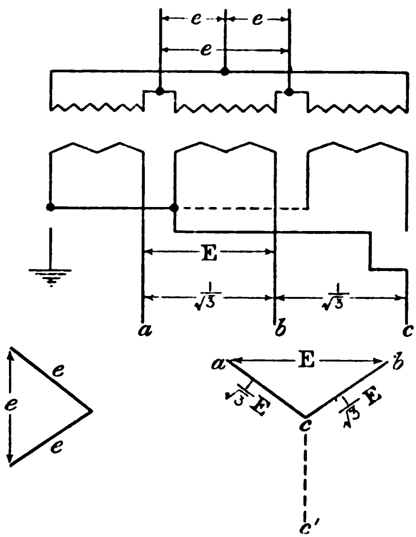


FIG. B.—Method of Operating a 3-phase Transmission Line with one Transformer Burnt Out, using the Third Conductor Charge Connections at Receiving End to Correspond.

a boon to many. The word "bushing" mentioned by Mr. Clothier represents an insulator, that is, an insulator bushing. The particular one in question is of a concentric design and filled with a special compound to operate on 100,000-volt circuits and above. The primary relay is provided with a series trip coil and operates under excess-current conditions. Electrically operated primary relays open the switch, as stated above, but the switch is closed again by hand.

I doubt if I can give Mr. Clothier the exact reply he asks regarding the differential time limit relay, but the following explanation of one such relay, which has been on the market for a number of years and given entire satisfaction in cases of severe overloads and short circuits, might help him. The differential elements consist of two independent

windings, one connected to a series transformer and the other to a potential transformer, the magnetic effects of these two windings under normal conditions being opposed to each other. The "time" elements are arranged for a definitive time or inverse time limit as desired, and are of the bellows type (closing or opening). An adjustable valve in the bellows determines the rapidity with which the air can escape and gets the time limit for any given load. Under conditions of overload, or short circuit the inverse time limit operates in inverse rates to the strength of the current; therefore the heavier the overload or short circuit, the worse the rapidity with which the relay will operate. On reversal of current, the two windings assist each other and the relay operates, as, for instance, at 1 ampere reverse current and 11

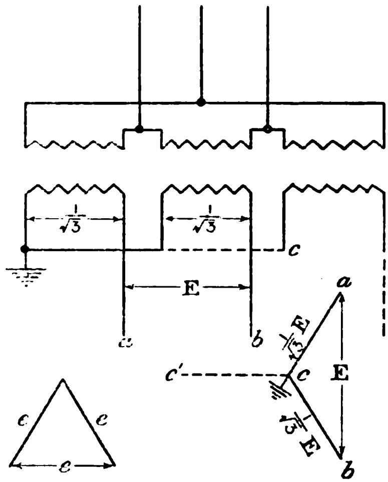


FIG. C.—Method of Operating a 3-phase Transmission Line with two Transformers and two Conductors—assuming the Broken Conductor is off the Ground.

amperes overload at normal potential the relay will operate; also at one-half voltage the relay will operate at 3 amperes reverse current and 8 amperes overload. It would take up too much time and paper to mention all the courses of actual breakdowns that occur on, say, only one transmission system operating in each country. I have been actually engaged on systems operating hundreds of miles of line, and conditions, character, and equality of kilowatt load have been such that it has not taken the chief operating engineer longer than five minutes to get changed over and to put things in regular working order again. On another system which operated a sub-station and transfer switch house to transmission lines leading out to a distant sub-station, the two aggregating a distance of 175 miles, and with 50,000 k.w. passing through the first sub-station, it has taken quite 15 minutes to get

the whole system in regular running order. The duration of time depends on the kind of breakdown which may be either in the machinery or transformers at the generating station—on the line—in one of the receiving station transformers, or in a series transformer. If in the latter, the circuit is interrupted until the series transformer has been disconnected. Mr. Clothier should begin from the generator end and proceed along just as if he was actually starting up each plant—close and open the different sections of busbars before and after synchronising or taking out of a unit (respectively), etc., he will quite unconsciously gather more information about how and why certain relays operate, etc., than can possibly be given in fifty pages. I should not recommend one kind of lay-out for every generating station or sub-station as the voltage, kilowatt capacity, distance of transmission, character of load, source of power, etc., would decide the right kind of design. The principal reason, or the only reason why a generating and receiving station of large kilowatt capacity receives so much attention and protection by means of relays, is because there is concentrated under one roof a great amount of money in the form of machinery and apparatus which must be protected against such things as short circuits from each other on any portion of the system, arranged for transfer from any one or more generators to any one or more groups of transformers, and transferred to any section of a double or single set of busbars on both the primary and secondary sides. The last point of protection is where the lines go out and come in the generating and receiving stations respectively. Although a long-distance transmission line is and always will be the weakest link of a large system, the right protection for interior and exterior interference at generating and receiving stations cannot be neglected. It is commercially impossible to run long-distance lines, *i.e.*, not less than 100 miles long (not as Mr. Clothier might have in mind, a group of ten lines 10 miles long), as outlined by the speaker. Branch lines taken off from these long lines are, in the majority of cases, taken care of, should a fault occur, by means of primary relays, called by some companies series overload relays, and by others expulsion fused switches. The protection scheme which all the huge transmission companies are trying to solve is on the main lines themselves. Take, for instance, a line from Manchester to London carrying 50,000 k.w.; would it, in the estimation of Mr. Clothier, be a matter of cutting out the faulty part and leaving probably the principal part of London's stores in utter darkness, subject to a penalty fine of something like £1,000 per hour? After all, it might be better to look closer into all those methods mentioned in the paper and adopt a method similar, though somewhat modified to suit local conditions and the amount of money to spend, the latter being the most important problem where protection of long-distance transmission lines is concerned.

The question of foundations for wooden and steel poles or towers as mentioned by Mr. Esson should not refer to the United States only, as the same method is followed in various parts of the

world. One company has at the present time over 250 miles of 60,000-volt steel transmission tower lines, the towers being set directly into natural soil. It is strange that nothing has been mentioned by the speakers about the kind and quality of galvanising of steel towers. In the field, engineers sometimes desire to know the quality of galvanising before setting their towers into the ground. The method usually applied to know the quality of galvanising is to immerse a part of the tower, as, for instance, a brace rod in a solution of copper sulphate for one minute, after which it should be taken out from the solution and immediately washed and thoroughly dried. This process should be repeated three or four times to see if any of the zinc has been removed or a copper-coloured deposit left on the surface; if so, the galvanising is of a poor quality and may be rejected. A standard solution of copper sulphate should consist of commercial copper sulphate crystals in water, and should have a specific gravity of 1·185 at 70° F. During the galvanising test of any of the parts of a tower, the temperature of the standard solution should not be less than 60° F. nor more than 80° F. Quite a number of engineers think like Mr. Esson as to the use of a delta connection on 100,000-volt lines and wonder why the extra expense involving this connection of apparatus was made. Experience led me to differ in this respect, and I believe the majority of engineers who now think the delta was a mistake will change their views five years hence, as by that time the additional load and the experience gained with their present line insulators will necessitate a change to the star connection, the change involving no extra expense, whereas, had the apparatus been bought for the lower star connection either the cross-section of the conductors would have to be increased or the entire system of transformers "scrapped" or re-designed for a higher voltage. The line surges due to opening of loaded lines or short circuits is a function of the current flowing in the line and is less marked at 100,000 volts than at 60,000 volts. It is quite economical to build 60,000-volt lines 14 miles long. Of course, Mr. Esson does not for one moment think such a voltage is used for loads of 100 k.w., nor designed for loads of 10,000 k.w. Whenever such a voltage is decided upon it can be taken for granted that the demand for power is large.

I quite agree with Dr. Kloss that Continental engineers have gone a great deal into the study of high-voltage transmission and have already built a number of high-voltage lines in Europe and other parts of the world. A few weeks ago I paid a visit of inspection to some plant built by Siemens-Schuckert for the Empreza Luz and Força da Ribeirão Preto, Brazil. The transmission line poles are of reinforced concrete, the conductors of copper cable, length of transmission 70 kilometres, and voltage of the line 33,000 volts.

Mr. Woodhouse states that insulators have not reached their final type, but his statement that "the designs shown are much too heavy, and mechanically defective" is not clear. The best 3-phase transmission line end connections for long lines and high voltages to minimise changes in phase relation, no matter what the fault may be,

in the transformers at either end of the line, is the delta-star raising and star-delta lowering. With this method of connection it is impossible to get a higher voltage as would be the case with the delta-delta to delta-delta or star-delta to delta-star or star-delta to star-delta. It is possible with any of these latter methods to obtain a change in the phase relation that might raise the voltage at the receiving end $\sqrt{3}$ times above normal value. For the same kilowatt capacity the surges mentioned by Mr. Woodhouse must necessarily be less with a delta-star to star-delta system than a delta-delta to delta-delta system, as the voltage surge is a function of the working current flowing in the line. Such experiences as those cited by Mr. Churton relative to trouble from lightning on the lines feeding Montreal have been the making of most of our best transmission engineers.

The figures given by Mr. Welbourn as representing the best pole-line construction in Great Britain do not compare with those given in the reply to Mr. Vernier's remarks. The line in question was built to carry 5,000 k.v.a. The method used for grounding steel towers is to leave them just as they are unless a concrete foundation has been built under them at least a foot above the surface of the ground, in which case the usual ground-plate is used. With wooden poles the best practice is to ground at every pole to a 12 × 12 × $\frac{3}{16}$ in. galvanised iron plate dug deep into the ground. Another method is to ground as stated on page 539 when a double set of poles is used—this method was used by myself when engaged with the Jhelum River Power Company, Kashmir, India. On all systems where the voltage of transmission is as high as 60,000 volts no special method is necessary to trip the relays or breakers in case of a fault on the line; the method of grounding the system is explained in the paper. The method of placing a long sleeve over the line wire to avoid any charring of the conductor in case of flash-over is not a good one. It would be much better to spend the money and time in an ordinary tie-in clamp which serves the purpose of the sleeve and binding-in wire. I have never known an insulator stand up long enough to permit sufficient discharge to burn the line conductor. It would probably stretch and finally break before such a condition really happened. The condition of load mentioned on page 12 is nothing like that Professor Parr speaks of. It is all practically due to the charging current on the line, and may be expressed as—

$$\text{k.v.a.} \div E = I_c'$$

and—

$$I_c' \times E = \text{k.v.a.} = 70 \times 100{,}000 = 7{,}000 \text{ k.v.a.}$$

There is a chafing of the line conductors due to the action of the wind, but it is very slight, and it has not yet given any trouble to any transmission system so far as is known.

Mr. Thursfield refers to the switch question. There are five switches, as he states, all of which are installed outside the sub-station. It is just as easy now to manufacture 100,000-volt switches as it was five years ago to manufacture 10,000-volt switches. The new type of

oil-switch for high voltages has got over a difficulty that most engineers were afraid of. Referring to Fig. 9, none of the switches shown can possibly be omitted. Three of the five 100,000-volt switches are of the air-break lever disconnecting type, and are principally used as a safeguard to admit repairs and cleaning of the oil switches, also to avoid the presence of a static charge on the oil switches and other parts of the system. The two remaining switches are oil automatic or non-automatic switches as desired; these switches are used to open the circuit on load or exciting current of the transformers, air-break switches never being used for these purposes. The correct operation of the switches Mr. Thursfield has followed out in the wrong order. The switch next to the sub-station is intended only for switching No. 2 bank of transformers over to No. 1 transmission line and *vice versâ*. There are so many variables for different systems that it is practically impossible to make a standard cost per kilowatt-hour for hydro-electric developments. The cost of machinery, apparatus, etc., can be safely placed at from 35 to 100 per cent., landed at the docks in this country, above the prices in Great Britain. This does not include the high expense of necessary supplies bought in this country for the construction of plant, nor the freight, cartage, and labour, all of which more than doubles the cost.

With reference to the lay-out of switches shown in Fig. 9, page 523, I am personally acquainted with the consulting engineer and designer of this station, and am very well assured that every detail of its design has been figured out to the best efficiency of the plant at the least expense, and that nothing extra in the form of switches or anything else has been included in its design that could possibly be omitted. For the majority of engineers not in any wise familiar with plants of this magnitude I grant that it is possible for them to state off-hand that it is correct and quite safe to operate a 100,000-volt plant, using the usual 6,000-volt lay-out of switches, relay arrangements, etc., designed for the 100,000-volt system. The nearest to this I have ever known was the California Gas and Electric Corporation. This Corporation at one time operated their plants in a very daring manner, not a single protective device other than a fuse wire being used on any part of their system.

In reply to the question asked by Mr. Gillett, I might say that steel towers are at all times made up in the field, that is, at the point where the tower has to be placed. It is not practice to run telephone lines on the same tower lines—this refers to 100,000-volt lines; it still remains the practice to string telephone lines on 60,000-volt lines, that is, on the same towers, although most companies have an independent line, and use it most of the time. It sometimes is a difficult matter to get good linemen. I have constantly employed men at 1s. 10d. to 4s. a day, whose duty it was to work on live 2,300-volt lines throughout the day and sometimes on a dark night—rubber gloves were given these men, but they preferred to work with bare hands. We never cut out any live 2,300-volt line when desiring to connect up distributing light

and power transformers of from 2 to 150 k.w.; of course all the poles are of wood, and primary cut-outs come between the transformer and live line. This practice is not a common one, but is nevertheless used by a number of companies in U.S.A. and Mexico. I have always endeavoured to avoid it where possible. The present practice of transmission engineers is to transpose the telephone wires, not the power wires. If Mr. Gillett refers to the transmission system shown on page 525 in his question "Is only one transposition made for the whole length, or none at all?" I reply that only one other transposition is made, that is, two complete transpositions in a distance of 87 miles, but the telephone line is transposed at about every fifth pole.

I beg to thank Mr. Snell for so kindly helping me out with some of the questions asked and placing his valuable experience at my disposal. Mr. Snell says " . . . We are very much indebted to our American brethren for the information they give us." I take it that Mr. Snell is under the impression that I am an American, but with due respects to him and the Institution, I am an Englishman. During a number of years of travel around the world I have met a number of Englishmen who are keenly following up high-tension transmission work, and from some of these I am confident we shall hear as time goes on. It is gratifying to know that the Metropolitan Electric Supply Company of London are about to construct a high-tension direct-current system. It is very doubtful whether manufacturers will make steel towers of the tubular type and of the same weight as cheap as towers made up of angle iron such as shown in Fig. 30. A very weak point about the tubular design is the connection of each member, for, as I understand from Mr. Fox, the main object of strength rests in its form, which is flattened out where connections are made. The number of towers that can be raised in one day of ten hours was given in the reply to Mr. Vernier, to which I would refer Mr. Fox.

Along with other speakers, Mr. Jacob brings up the question of aluminium for transmission lines. One kind of conductor was not mentioned any more than another; in any event I did not intend to speak of the qualities of these two conductors nor to compare their cost per pound per given length and conductivity. However, a few words in this direction might not be out of place. In North America it is stated that aluminium at 62 per cent. conductivity, bought at 2·13 times the price of copper per pound, will give the same length and conductivity for the same temperature. This rule may not apply in any other part of the world, but is a close one to follow when comparing the price of copper and aluminium on this basis. In this country we have to pay duties as follows: 1s. per kilogram on copper and 3s. per kilogram on aluminium. Due to the high coefficient of linear expansion and low tensile strength, the minimum allowance sag for aluminium wire is considerably greater than for copper. For long spans the difference in deflection between aluminium and copper wires may be so great as to require a higher pole or tower in case aluminium

is used, although the structure used need not be so strong as would be required for copper, as the weight of aluminium for equal conductivity is but 47 per cent. of the weight of copper. As greater care is necessary for stringing aluminium than copper wire and its general handling, it costs more to erect. In the early history of the use of aluminium for transmission work, good jointing became quite a big drawback. I have in mind a certain aluminium sleeve or turn-buckle that I sent to England in 1903 from Waterburg, Conn. (the New Milford Power Company). A number of engineers there deliberately contradicted the statement that such a thing was ever used on a 33,000-volt transmission line, and, strange to say, some of them stated that no such voltage line was in existence. I went to work and took a large number of photographs at a close range showing a portion of the transmission line, and also sent about a foot-length of the stranded conductor with a No. 2 aluminium turn-buckle, also a couple of photographs showing transit oil in a frozen state. With reference to snow collecting on this transmission line, the winter of 1903 was a record for some years past for snow and thickness of ice (30° below zero was recorded in the 33,000-volt sub-station), there seemed to be less than was collected on the copper distribution lines. Aluminium may be used exclusively in generating and receiving stations operating at high voltage—a great amount of copper now employed is put in simply for mechanical reasons—the same size copper can very well be replaced with aluminium at a reduced expense. For low or moderate voltage plants, busbars are designed to have a stated carrying capacity limited by a given temperature rise—thus, the aluminium busbar having a greater radiating surface is enabled to carry a greater current than a copper busbar can with the same rise of temperature. By English engineers at home it is often stated that the Americans go the limit, that is, cut down the safety factors to the smallest fraction. This may or may not be the case, but nevertheless there must be some reason for it, if it is done. Mr. Jacob has brought up a very important question here, a question that should be carefully gone into not only for overhead transmission lines, but for a great number of other things quite as important. Canadian transmission lines and every other big line in other parts of the world are built with lower safety factors than English lines, and they stand up and give satisfaction under worse climatic conditions than England ever experiences.

Mr. Greene asks if the dynamometer is used to get the actual tension on the conductors. The dynamometer is only used by men not experienced in the erection of lines—on starting out with the first few reels of conductor the dynamometer is always used; after this an experienced lineman can tell just what sag to allow. No transmission line is ever built to a table, although one is mapped out and the pounds pull given to the line superintendent. One or two spans are measured, after which the linemen allow for a similar sag on all similar spans; where spans are long the dynamometer is used. The McIntyre joint is used on transmission lines all over the world with entire satisfaction both for

copper and aluminium lines. A similar double-sleeve joint is used for transmission telephone lines. The Britannia joint well made is probably better and stronger than the McIntyre joint. Most of the trouble on aluminium transmission power and telephone lines is at the point where the binding-in wire or clamp is fastened at each pole or tower, as with constant swinging of the conductor it becomes crystallised and finally breaks where the binding-in wire or clamp grips similar to a break of a trolley wire at the ear from constant raising and lowering of the conductor as the trolley passes underneath.

Mr. Rayner is quite right in saying that a machine of 500 k.w. would simply burn out if placed on the line mentioned, and the explanation he gives will cover the remarks of Professor Parr on this matter. The one-terminal high-voltage transformer connection will reduce the expense of the transformer as has already been known in America for some years,* but it spoils the flexibility of the transformer should any other connection be required for temporary needs at a lower voltage on some other system. It has often happened that the overhead ground wire has not been thoroughly clamped down to the tower; when this occurs, a bad ground connection is made, and a person passing by might receive a shock should the towers happen to be set on concrete foundations elevated above the surface of the ground. There are many good reasons for speaking well of the aluminium type arrester, but I do not think it necessary to dwell on this subject, seeing that it was thoroughly covered not long ago in a paper by J. S. Peck.† All transmission engineers have their troubles with lightning, and if all the stories could be told of lightning behaviour we should have some very interesting data. The transmission lines of the Light and Power Company of Puebla, Mexico, traverse the cañons and plateaus of that portion of the Republic at an altitude varying from 6,000 to over 14,000 ft. Also, the network of power lines of the Animas Power and Water Company traverse Southern Colorado, U.S.A., at altitudes varying from 9,000 to 13,300 ft. It was found that air has a definite breakdown strength; that is, just as a beam breaks mechanically as soon as the stress in it exceeds a definite value, so air breaks down by a disruptive spark as soon as the electric stress in the air exceeds a certain value, which is about 100,000 volts per inch. The disruptive strength of air is, over a wide range, proportional to the pressure; that is, at a pressure of two atmospheres it is twice as high, or 200,000 volts per inch; at one-quarter atmosphere it is 25,000 volts per inch. The striking distance in air between needle-points has been investigated up to 300,000 volts, and for high voltages it is found to be very nearly 10,000 volts per inch. For voltages above 33,000 the aluminium arrester is exclusively recommended. This type of arrester is principally designed for continuous discharges which are as a rule of comparatively low frequency. Even where the multi-gap type of arrester is used it is advisable to install one or more aluminium cell

* *Transactions of the American Institute of Electrical Engineers*, vol. 23, p. 228, 1904.
† *Journal of the Institution of Electrical Engineers*, vol. 40, p. 498, 1908.

arresters to relieve the system of such discharges and prevent other types of arresters from discharging continuously until they are injured. When the two types are used the horn-gaps of the aluminium cell arresters should be set at a voltage somewhat under the sparking voltage of the multi-gap arresters which are to be placed on the line, so that if continuous surges take place on the line, the aluminium arresters will take care of the discharges. In a cold climate it is recommended to install this type of arrester indoors, as the electrolyte freezes at about 20° F.; furthermore, since it will continue to discharge until the trouble is removed, it should be installed where there is an attendant to note the discharge and take steps to locate the trouble and remove it. They will discharge continuously for one half-hour, sufficient oil being provided to absorb the heat generated. The most important characteristic of this type of arrester is its critical voltage, which depends upon an hydroxide film of aluminium formed on the surface of aluminium plates by putting them through chemical and electrochemical treatments. Up to a certain voltage the cell allows an exceedingly low current to flow, but at a higher voltage the current is limited only by the internal resistance of the cell which is very low. A close analogy to this action is found in the well-known hydraulic relief valve. On the aluminium plates are myriads of these relief valves, so that if the electric pressure rises above the "critical voltage"—*i.e.*, the voltage at which the current begins to flow freely—the discharge takes place equally over the entire surface. The aluminium cell acts as a fairly good condenser, and there is not only the leakage through the film, but also a capacity current flowing in the cell. The phase of this capacity current is nearly 90° ahead of the potential, and represents a very lower power factor. Another very important characteristic of this arrester is the dissolution of a part of the film when the plates stand in the electrolyte and the cell is disconnected from the line. The film is composed of two parts: one part is hard and insoluble, and apparently acts as a skeleton to hold the more soluble part. The action of the cell seems to indicate that the soluble part of the film is composed of gases in the liquid form. When a cell which has stood for some time disconnected is re-connected to the line, there is a momentary rush of current which re-forms the part of the film which has dissolved. This current rush will have increased values as the interval of rest of the cell is made greater. Many electrolytes have been studied, and no electrolyte has been found which does not show this dissolution effect to a greater or less extent. If the cell has stood disconnected from the line for some time, especially in a warm climate, there is a possibility that the initial current rush will be sufficient to open the circuit-breakers or oil-switches. This rush of current also raises the temperature of the cell, which is objectionable. When the cells do not stand for more than a day the film dissolution and initial current rush is negligible. This type of arrester consists of a series of concentric inverted cones placed one above the other with a vertical spacing of about 3 in. The electrolyte is poured

into the cones and partially fills the space between adjacent cones. The stack of cones with the electrolyte between them is then immersed in a tank of oil. The cones, except for the electrolyte, are insulated from each other, the oil improving the insulation as well as preventing the evaporation of the solution. A cylinder of insulating material concentric with the core stack is placed between the latter and the tank containing the oil. A separate stack of cones with tank are used for each phase—for non-grounded lines—and for lines grounded through a resistance, an additional stack and tank is used for the grounded wire. It is important to see that the right kind of arrester is used for the particular connection of the line, with dead grounded neutral or partially grounded neutral. In an arrester for a dead grounded neutral system, each stack of cones normally receives the neutral voltage when the arrester discharges; but if a phase becomes grounded, line voltage is thrown across each of the other stacks of cones until the oil switch opens the line. Line voltage is $\sqrt{3}$ times the neutral or normal operating voltage of the cells, and therefore about 150 per cent. of the permanent critical voltage of each cell. This means that when a grounded phase occurs, this 50 per cent. excess voltage is short-circuited through the cells until the oil switch opens. The amount of energy to be dissipated in the arrester depends upon the kilowatt capacity of the system available, the internal resistance of the cells, and the time required to operate the oil switch. In cases where the neutral-point is partially grounded through a resistance, the oil switch will not open instantaneously—a four-stack arrester is provided for this method of earthing. Lines with dead grounded neutrals are provided with a three-stack arrester. The basis of the stacks of cones are connected to the tanks and grounded. The top cone of each stack is connected to the line through a horn-gap.

This type of arrester is not made to be connected permanently between lines and ground. A horn-gap, set at a suitable value above line voltage, is inserted in series, and prevents the arrester from being subjected continuously to the line voltage; in this way leakage is prevented at normal voltage and a longer life of the cones is insured. These horn-gaps (one per phase) connected between the line and arresters serve as disconnecting switches to disconnect the arrester from the line for repairs, inspection, or daily testing, etc. Disconnecting is accomplished by pulling a rope which releases a latch, thus allowing the coiled springs to turn the movable horns through a large angle that provides ample safety. A transfer device is provided with each set of arresters, the object of which is to interchange the ground tanks with one of the line stacks of cones during the charging operation, so that the films of all the cells will be formed to the same value. This device consists of a rotating switch which may be turned 180°, thus interchanging the connections of the ground tank and one of the line tanks. It is operated by a bevel gear up to 70,000 volts, and by sprocket wheel and chain beyond that voltage up to 110,000 volts. The charging operation in the case of arresters for grounded neutral systems

consists of closing the three horn-gaps simultaneously, so that full voltage across the cells causes the charging current to flow and form the films up to their normal condition. With arresters for non-grounded lines, the charging operation is as follows: (1) The horn-gaps of the arresters are closed for 5 seconds and opened again to normal position, thus charging the cells of the three line stacks; (2) with the horn-gaps still in position, the position of the transfer device is reversed and the horn-gaps again closed and instantly returned to the normal position. The complete charging operation takes but a moment, and should be performed daily. The operation is valuable, not only to keep the film in good condition, but also to give the operator some idea of the condition of the arrester by observing the size of the arc which forms during charging. For 70,000 to 110,000 volts the horn-gaps have been specially designed to prevent all corona and brush discharge. This is accomplished by doing away with all sharp corners and points on the clamps and connections and by making the horn of large copper tubing with spherical ends instead of copper rod.

The aluminium type of arrester for cable systems differs from arresters for overhead lines only in the construction of the horn-gaps. The necessity for this is due to the fact that a long cable system has a much higher electrostatic capacity and much less inductance than an overhead system. In consequence, the currents which flow into the arrester during charging are somewhat higher. A safety horn-gap is therefore provided with a resistance auxiliary to intercept the arc if it arises on the ordinary horns. In all lightning arrester installations it is necessary to provide a path to the arresters and ground with as little impedance as possible. In order to achieve this purpose rather large wires with long bends and turns would have to be used. Now, it is well known that high-frequency lightning disturbances are confined to the outside surfaces of the conductors, penetrating but little towards the centre, hence by using either flat strip or tubing the advantage of a larger conductor—*i.e.*, a large surface—is secured, but at a less cost. Copper tubing has the advantage over either strip or solid conductors in that it is easily supported, requires fewer insulators, and is therefore the cheapest to install. The copper tubing is so designed that when the wiring is complete all joints are flush, all sharp bends are eliminated, and there are no points where corona or brush discharge will take place. Discharge alarms are now made that indicate discharges through the arresters. The discharge alarm will indicate the existence of a grounded phase on non-grounded neutral systems; but it does not give a record of the discharges nor operate on discharges not due to grounded phases. A knowledge of all discharges is of immense value to operating engineers in studying conditions of abnormal voltage on transmission and cable systems; but heretofore the only way of observing the discharges was to watch for them at times when they might be expected. It is, however, impossible to watch the arresters all the time, and there are, furthermore, a large number of discharges which can hardly be detected even by watching the

horn-gaps. In order to get an exact record of the number of discharges, a discharge recorder has been designed, which consists of four spark-gaps so arranged that the discharges between lines or between lines and ground pass through the gaps. The spark-gaps are assembled with a clock-operated drum in such a manner that a continuous record is obtained of discharges by punctures in a moving roll of paper. This paper passes through the gaps at about 3 in. per hour, and thus gives a very accurate record of the time and duration of each discharge. Besides being valuable in recording discharges due to abnormal voltages on a system, the discharge recorder is of value in indicating and recording the daily charging of the arrester. With such a recorder it can be told whether or not the arresters are being properly charged by the station operator, and the punctures give some indication of the condition of the arresters. If the record shows that the charging current is abnormally large, steps could be taken to examine the arrester for discharges due to neglect or carelessness.

As has already been stated in the paper, in all lightning arrester installations it is of the utmost importance to make perfect ground connections, as a large majority of lightning arrester troubles can be traced to the lack of this precaution. It has been customary to ground a lightning arrester by means of a large metal plate buried in a bed of charcoal at a depth of 6 or 8 ft. in the earth. A more satisfactory arrangement of making a "ground" is to drive a number of 1- to 2-in. iron pipes 6 or 8 ft. into the earth at several points about the station where the arresters are to be installed, connecting all of these pipes together by means of copper wire or, preferably, by copper strip. A quantity of salt should be placed around each pipe at the surface of the ground and the ground thoroughly moistened with water. It is advisable to connect the pipes to the iron framework of the station, and also to any water mains, metal flumes, or trolley rails that are available. When plates are placed at a distance from the arresters, it is advisable to drive a pipe in the earth directly beneath the arrester, thus making a ground connection as short as possible. For non-grounded neutral systems another kind of discharge alarm is made which consists of a single aluminium cell placed on the ground connection of the arrester, and an electric bell or auxiliary relay in shunt with the cell. Whenever current passes through the ground circuit the bell rings, or the relay closes a signal circuit, which calls the operator's attention to the discharge of the arrester. One of the severest conditions to which an arrester may be subjected is that of an accidentally grounded phase on a partially non-grounded line. A grounded phase may produce continual discharges through the arrester for a long period, and while the aluminium arresters are designed to withstand such discharges for at least one half-hour, it is evident that if the discharge lasts for long the arrester will gradually heat and may be damaged internally owing to the leakage current due to the warming of the electrolyte. To prevent this, all arresters for non-grounded lines should be provided with discharge alarms.

As Mr. Lee is probably the only one amongst the speakers who had had actual experience in the operation of long-distance transmission systems, I think he will agree with me that transmission engineers have good reason to complain of the behaviour of some of their arresters, and that not only is the system disturbed but sometimes shut down from the result of a severe discharge over the arresters. Mr. Brazil rather doubts the fact that any system can be disturbed from the result of a discharge over the arresters—he has probably forgotten that a disturbance as mentioned in the paper might be the result of a certain system of connections, as, for instance, a delta-star with an accidentally opened delta multi-gap type of arrester; or no arresters at all beyond a widely separated set of horns with a certain oil-immersed resistance on the ground side, etc. I am not the only one who can, if necessary, give some sad experiences of lightning arrester troubles on systems varying in voltage from 33,000 to 100,000 volts. Up to the present time, I have only heard of one company (which operates part of its lines above 14,000 ft. altitude) which has had a bad word to say against the aluminium arresters, and even this seemed rather unreliable, as they soon afterwards bought aluminium arresters from another manufacturer. The only 60,000-volt horn-type arresters I have seen in operation were in California during the year 1905. They had widely set horns, about 6 in. separation between the gaps, with a non-inductive resistance in series between the arrester and ground. These arresters were always installed out-of-doors, and a good thing, too, as when they discharged the whole country was illuminated and the entire system received a shock, sometimes so bad that there resulted a general shut-down. I quite agree with Mr. Brazil that a resistance should be always placed between the arrester and ground, but the resistance must be non-inductive, or else conditions will become worse. The experience cited by Mr. Brazil is rather interesting; but to explain correctly the exact cause of the rise in voltage is difficult, unless something was wrong in the transformers, and the system was a mixed overhead and cable network, the line being connected at both ends in star.

As stated by Mr. Isaacs, further increase in voltage is limited by the production of corona. The kind of conductor referred to has been in commercial use for transmission line purposes for a number of years. It has an advantage over the solid conductor, and will reduce slightly the corona effect. The skin effect increases with the frequency, and also with the diameter of the conductor in such a way that for the same percentage of increase in the resistance due to skin effect, the product $D^2 \times f$ is constant (where D^2 is the diameter of conductor squared and f the frequency of supply). It is well known that alternating current causes an unequal distribution of current in the conductor, the current density decreasing towards the centre of the conductor, so that for large wires the central portion is practically useless as a conductor. Voltage rises in transformers arise from lightning discharges, switching operations, resonance (depending on the kind of connec-

tion), and short-circuits. Since high-voltage transformers are seldom switched out from the high voltage side, all switching being done on the low-voltage side where possible, it is found quite sufficient to install lightning arresters in the usual place, *i.e.*, between the line oil switch and line disconnecting switch. Lightning arresters have been installed on the low-voltage side between generators and transformers, but never, to my knowledge, between the terminals of the high-voltage transformer oil switch and the transformer winding. It hardly seems necessary to place an installation of arresters at this point of the system, as the ordinary installation, as represented in Figs. 2 to 11, will take care of any increase in voltage arising from a short circuit on the transmission line. The aluminium arrester is especially designed to relieve the current surges on an insulated system, where, say, one of the phases of a 3-phase system is grounded through a flaring arc; and since it can be connected directly to the line for over one half-hour at a time, it gives very good conditions for relieving continuous strains on the line.

As regards the public service restrictions coming into force on the Pacific coast, mentioned by Mr. Lee, it does seem a little dangerous to run 60,000-volt lines through thickly populated streets, as could be seen in certain parts of Oaklands, California, at least, during the time I was connected with the California Gas and Electric Corporation. Such was the case, not only in that particular city, but in several others. Fig. D represents a type of modern high-voltage oil switch mentioned on page 521. As will be seen, the break is vertical—operated in this case by hand—and set directly on the floor of the station, thus doing away with expensive masonry cells and leakage of oil-pots, which are two of the greatest drawbacks of the older type high-voltage oil switch. The oil switch used on the entire system of the (late) California Gas and Electric Corporation is of local manufacture, and so far as I can say, it has always given satisfactory service so far as breaking the circuit under load is concerned. The switch operates on a pivot, thus breaking on both sides, the breaking distance being about 4 in. in oil for voltages up to 60,000. The design of the modern high-voltage oil switch shown in Fig. D has proved entirely satisfactory for voltages up to 100,000, and will remain a standard type for many years to come. Such details as the parallel motion of wooden guide rods, insulator bushings for the line side and switch rod, and methods of operation must necessarily change with the times, but the general design will remain standard for some years. The only disadvantage so far is mechanical, which particularly refers to the parallel link motion and setting-off springs. The steel tank of this style of switch must at all times be grounded, as well as all metal framework supporting the operating mechanism. While an oil break switch may be insulated for a given potential and constructed to carry a definite amount of current, it should not be understood that the switch will necessarily carry that amount of normal energy equivalent to the volt and ampere rating of the switch, in the event of a short circuit. A source of electrical energy may have

power greatly in excess of its normal capacity, and the switch may, therefore, be required to interrupt not merely the normal energy delivered to the circuit in which it is connected, but the entire power which may be developed under short-circuit conditions by all the generators and synchronous apparatus in parallel which are connected to the system. Under short-circuit conditions synchronous generators develop instantaneously many times the normal full-load capacity, while the sustained short-circuit current would be approximately 2½ to 3 times normal. Therefore instantaneous automatic switches must be capable of rupturing the circuit when the current is at a maximum,

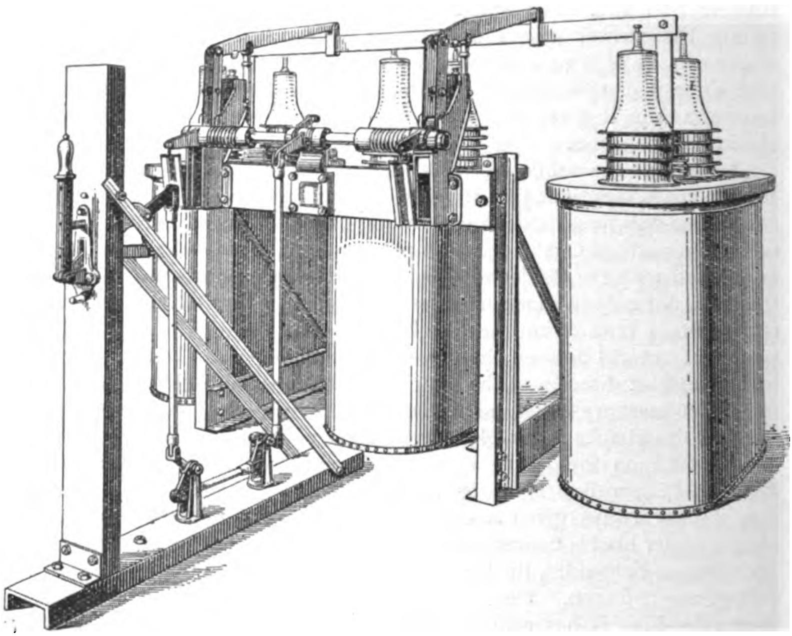


FIG. D.—Modern High-voltage Oil Switch.

whereas non-automatic switches and automatic switches with time-limit relays have to interrupt only the sustained short-circuit current. The reason is evident, since the delay in opening of the switch allows the current to settle down to approximately 2 or 3 times normal.

With a system operating many hundreds of 60,000-volt line (star connection at both ends, neutral ground), it is practically impossible to get satisfactory telephone service when the telephone circuits are strung on the same poles. Furthermore, with a slight leakage on the power lines the telephone circuit becomes dangerous to handle; in fact, any kind of unbalancing of currents in the power conductors will affect telephone communications. When telephone circuits are strung in this

manner it is always recommended to install telephone transformers. The telephone transformer is used to protect telephones from the dangers of high voltages due either to induction or to accidental contact where high-voltage transmission and telephone lines are on the same pole. This design of transformer has a 1 to 1 ratio. Ample insulation is provided between windings to withstand a high potential test of not less than 25,000 volts between the line and instrument. One test on a 30,000-volt transmission line in actual operation showed that a ground of one phase of the power system induced a potential on the telephone line of approximately 7,000 volts measured between telephone line and ground. Notwithstanding this high induction on the telephone line, it was possible to use the telephone when the transformer was installed, but absolutely impossible without it. The line was noisier than under normal conditions, as of course would be expected, but not so noisy as to prevent conversation, which would have been impossible without the transformer. The great trouble with most telephone lines is poor insulation of the lines themselves, larger insulators being required on practically all installations giving trouble. Another important matter very often neglected when building long-distance telephone lines is the number of telephones on the line and the resistance of bells. After a few months have elapsed it is often found that three, four, or more telephones have been added, and it is practically impossible to get a reply from one of the distance-points, principally the generating station, a near-by patrol station being called up to deliver the message to the generating station. This happens with or without the use of telephone transformers. With the use of telephone transformers, tests show that the magnetising current taken by the transformer is about 0·5 ampere passed by a standard 1,000 ohms bell. A combination of switch, fuse, and lighting arrester is always used with this transformer. The most interesting part of this combination is the arrester, which is of the usual carbon form with mica separation across the terminals of the transformer (not the ground). The gap between the telephone wires and ground is adjustable, and should be set just beyond the point where it will arc, due to the inductive voltage on the telephone line when one conductor of the power system is grounded. When an arc occurs from this cause the fuse will blow, thus cutting out the transformer and telephone.

The same company with which Mr. Lee has had his transmission experience, operated their 60,000-volt lines in star with delta on the low-voltage side of some receiving stations and star on others, the neutral-points of the high-voltage transformer windings being dead grounded. In operating long lines with a combination of transformer connections such as these there is a chance of trouble occurring similar to that mentioned by Mr. Brazil. As has already been stated, the delta-star to star-delta gives the best all-round advantage from both financial and maintenance points of view, the exact amount depending on the size of the system in kilowatts, length of transmission of the transmission line, location, and workmanship.

The Guanajuata Power and Electric Company was the first long-distance transmission system equipped throughout with steel towers for a distance of 101 miles from the generating station (Zomora) to Guanajuata, as far back as 1902, regular operating commencing in 1903. In the year 1906 the cross-arm arrangement was changed to make provision for an overhead ground wire; beyond this no further change from the original design of towers has been made. Another transmission steel tower line was built in the same country in 1904 (Mexican Light and Power Company), the total length of line from the generating station (Necaxa) to El Ore being about 170 miles. Another very large transmission system (Northern Mexico Power Company) is under construction in the northern part of Mexico. This system will have a large network of steel tower lines supplying power to all the principal cities and mining districts in the north. With the particular system of transmission mentioned by Mr. Lee it is absolutely necessary to have an auxiliary gas or steam plant at each receiving end mentioned, but the author fails to see why a relay of auxiliary plant has never been provided for at the capital (Sacramento). Within the last two or three years a number of electric power transmission companies have sold out their gas and steam auxiliary station machinery and apparatus, and the tendency to-day is to look more into the design and general lay-out and protection of the main lines and branch lines. On practically all the present-day transmission systems, synchronous condensers of some form or other are floated on the line for the improvement of power factor. A synchronous condenser will deliver 70 per cent. of its rated k.v.a. in energy and approximately 70 per cent. in wattless leading k.v.a. for power-factor improvement. Take a case where it is necessary to raise the power factor from 0·65 to 0·90, assuming a load of 450 k.w. This amount of energy at 0·65 power factor is 690 total apparent k.v.a. and has a component of $\sqrt{690^2 - 450^2} = 525$ wattless k.v.a. lagging. With this same amount of energy, and the power factor raised to 0·90, or 500 apparent k.v.a. the lagging component of wattless k.v.a. is $\sqrt{500^2 - 450^2} = 220$. Now, in order to raise the power factor from 0·65 to 0·90 it is obvious that a synchronous condenser with a rating equivalent to the difference between 525 and 220 is required, or $525 - 220 = 305$ wattless k.v.a. leading. On one system the author has in mind, this method of using synchronous condensers went too far at times, and one or more receiving stations where these units were installed had to cut out practically all the exciting current so as to reduce the voltage.

Mr. Lee states that the life of poles averages ten years. A short time ago a report on the preservative treatment of wooden poles was prepared in the United States, from which it appeared that there are required for pole renewals between 500,000 and 600,000 poles per year, and that during the next ten years this number will be increased to about 900,000 or 1,000,000. As the result of direct inquiry into this matter, to a large number of transmission companies, the life

of various timbers when used for transmission poles was given as follows :—

Life of Wooden Poles in the United States of America.	
Kind of Timber.	Number of Years.
Cedar	13·5
Chestnut ...	12·0
Cypress ...	9·0
Pine	6·5
Juniper ...	8·5

Mr. Rosenbaum is the only person who has a good word to say about the overhead ground wire. Not long ago Professor Jackson wrote a good paper dealing at length with the subject of losses, etc., very much after the remarks of Mr. Rosenbaum. The particular case given by Mr. Rosenbaum is but a very small fraction of 1 per cent. and might very well be neglected; but, as he states, for lower voltages and higher frequencies (assuming the same kilowatt capacity) the losses cannot be neglected. The expression, "equivalent resistance per mile," is not out of order, and must not be confused with (R) which is the actual ohmic resistance of the conductor per mile. The equivalent resistance divided into the actual resistance of conductor will give the power loss of the line, or—

$$p = \frac{r}{R} = \frac{\text{actual resistance of conductor}}{\text{equivalent resistance of line}}.$$

The size of system in kilowatts, length of transmission line in single circuit, voltage between phases, etc., corresponding to Table II., is—

Total generator capacity	40,000 k.w.
Total transformer capacity (including spare units)	65,000 „
Total length of transmission circuit ...	470 miles (nearly).
Line voltage	60,000 volts.

In Great Britain such a plant would be a commercial impossibility. Where it is, however, it is one of the best paying propositions in the country—little or no coal is mined, and all the coal used for railway purposes and auxiliary stations is imported from Great Britain or elsewhere. The same condition exists where I am at present engaged, therefore it is possible to transmit electric energy for long distances cheaper than shipping coal from Europe. In this country some large

power consumers generate their own power at an average cost of $030 (0.5d.) per kilowatt-hour. One hydro-electric power company sells to its large consumers at $025 reis (0.45d.) per kilowatt-hour; this is, however, an exceptional rate of charge for a country like Brazil. The prices for energy shown in Table VII. give the charges at two different stations and cover the losses of transmission to the different receiving stations. The generating station charges are not mentioned —the difference in charges between the two being about 10 per cent., which is considered quite ample for the system in question.

Mr. Scott has only taken into consideration the cost of poles of the transmission pole scheme shown in Fig. A (A and B). Leaving aside for the moment the first cost of these poles, there are a number of disadvantages in selecting a pole-line of this design for high-voltage work at from 33,000 to 110,000 volts. (1) The cost of insulators for B, to equal a line built for A voltage, will require not less than 30 per cent. more insulation because of the horizontal supports, or a span of not less than 30 ft. made up of 10 insulators between conductors and 7 insulators between outside conductors and pole or ground, in all 34 insulators. (2) The erection of either A or B is practically impossible if the conductors have to be higher than 50 ft., and they cannot be very much less for voltages of 110,000. Double step-ladders cannot be carried about the country to string wire, especially so when one of the conductors has fallen to the ground and probably the nearest step-ladder is 50 miles away. The pole is round in form and the span too wide to permit any other local means of stringing and tying-in the conductors. (3) There are about 40 weak points in the span B, counting from the pole on the left to that on the right, and about 20 weak points in A, counting each insulator unit and dead-ends at each of the poles, so that reliability of service is not very promising. (4) Poles of this design are not quite strong enough for constant spans of 450 to 750 ft., and if shorter spans are adopted the total cost of line will be greater than steel tower lines because of the great amount of insulators that will be required. (5) As high-voltage insulators are very heavy, and the weight and strain of span wire, which cannot be less in size than a ⅜-in. diameter steel cable (plus the snow and ice and wind strains, all of which are directly added to the line should the wind be coming at right angles to the direction of the line); much stronger poles must be used for the same weights and spans than would be needed in an ordinary 1-pole structure.

Any new design of pole structure is carefully considered by transmission engineers, and if Mr. Scott can give us a new design that will meet our needs without being too costly, he will have done much to both power consumers and power companies. This remark is not quite justifiable that, "The craze for steel towers has gone far enough." Where money and prestige are concerned there does not exist such a thing as "craze." If Mr. Scott can help us to a better transmission line practice we shall all be ready to follow, but he will first have to show us what is the advantage. Continuity of supply is, as Mr. Lee

pointed out, an absolute necessity to the success of any electric supply undertaking, and Mr. Scott cannot give us from the design shown in Fig. A (A and B) a better design than we already have or guarantee better service. One of the most important requirements in a long-distance transmission line is the need of securing continuity of service, and in this, the pole is not the part which gives the most troubles. If it were, such things as sectionalising switches and cross-over switches would not be of much use. Most of our troubles are with the lines themselves, and not with the poles or towers. To reduce these troubles, double circuits are used either on the same tower (a wooden pole being of no use in such a case) or on two adjacent towers or poles, switches being installed at certain sections of the line. In this manner a transmission line can be subdivided into certain unit lengths as conditions may indicate to be desirable, provision being made at the junction-points for cross-connection from one line to the other by suitable switches. In this way only a small part of one circuit of a 100-mile line would be out of commission, the remainder being in multiple through the corresponding good line. It is clear that by proper methods of operation an interruption to a line could be made of short duration. Some inventive mind may design a scheme by which automatic primary relays may be provided in such a manner that the relays in the line circuit will operate inversely to the relays of the cross-over switches; in this way transmission lines could be switched over as if nothing had happened. If this were made possible by means of automatic oil switches of the modern type, it would be necessary to know if a switch were out or not. To find this out, it would be necessary for the patrol-man on his daily round to ascertain the position of the switch mechanism. Our greatest difficulty in a switching method of this kind is the possibility of throwing out of synchronism a big part of the system unless the relays are made instantaneous: even then the scheme is risky. It might be better to have a time-limit overload relay of, say, 5 minutes duration. No matter what the scheme may be, the main object in view is continuity of service, and the method proposed is toward that end.

Mr. J. F. C. Snell (on behalf of Mr. W. T. Taylor): Not being the author of the paper, but merely holding a watching brief, I will ask you to forgive me if I do not reply exhaustively to all the points raised. Some of them I must pass on to Mr. Taylor. Mr. Churton referred to the relative cost of overhead lines and underground cables, and Mr. Welbourn gave some figures on this point, stating that single overhead line construction would cost £800 per mile. Knowing the approximate cost of the pole line, I take it that that really represents about £1,200 for a double line, each line carrying the same load. The ratio of underground cable to overhead lines for equal transmission facilities is therefore practically as three to one. That I presume refers to a 20,000-volt line, a good deal of which has been constructed by him on the North-East Coast. The point is that the

copper is practically the same, and it simply becomes, therefore, the relative costs, on the one hand, of the poles and wayleaves in this country, as against the cost of trenching, insulation, and jointing of the cables. With regard to Mr. Churton's remarks respecting the storm at Montreal, I presume he was referring to a line where they have single insulation. I understood him to say the voltage was 60,000. The same effect of course would not have happened with the suspension type of insulator. As Mr. Woodhouse mentioned, these very high pressures do not apply, and perhaps never will apply, in this country. As I remarked, however, we must as engineers take an active interest in this high-tension transmission, because many of us may be called upon to carry out schemes in other countries. At the present time my firm is carrying out a 50,000-volt system in New Zealand. I have not yet had any experience but have to gain it, and we are very much indebted to our American brethren for the information they give us. I hope British engineers will be found to the fore in carrying out some of the future high-pressure schemes throughout the world. The author is, of course, one of them.

Corona, I take it, at high voltages depends to a great extent on the dielectric strength of air. If the air is not pure, then the dielectric strength of the air is less, but I have heard it said that humidity does not greatly affect this. I believe that is on the authority of Professor Ryan, to whom Mr. Woodhouse referred. With regard to delta-delta connections, there is some advantage in this. If we have the delta on one side or the other, one thing results, viz., the absorption of third harmonics, which circulate around the coils, and also if one arm breaks down a 3-phase supply can still be maintained. The extremely interesting remarks of Mr. Farrand with respect to the life of wooden poles represent, I believe, the general experience of his department, viz., an average life of 35 years being obtained. Where the author speaks of a general life of 12 years, it must be remembered that he refers to American, and particularly Californian, practice, and he is probably referring to different kinds of wood, which would affect the life considerably. Perhaps also they are untreated poles, being cut down and erected *in situ*. I cannot say how the grounding is carried out, but the author relies on carrying the steel tower below the bed of concrete, and some extra earth plates may be fixed where necessary. Mr. Thursfield referred to the number of switches shown in Fig. 9. They are isolating switches and are necessary to enable the oil-break switches to be completely cut out for examination and repair. He also referred to the high cost per k.w. in Table II., which works out at £40 per k.w. I should imagine, as Mr. Matthews pointed out, that Mr. Taylor was probably referring to his own Mexican system, which is a plant of 75,000 k.w. In any case, in comparing the price we must bear in mind Mr. Churton's remarks that the cost of material over there is about double what it would be in this country. The capital charges are the principal charges in all large hydro-electric schemes. With reference to Dr. Pohl's remarks on the flash-over

at 90,000 volts, I think he has misread the author's remarks. As I read it, it means that we test each insulator separately and get 9,000 volts; if we put four of these in series we shall not necessarily get 36,000 volts, but something less. The Metropolitan Electric Supply Company in this country are actually going to instal a system of direct-current high-tension transmission from the Willesden power station. I am not sure whether it is yet actually constructed, but we shall have a high-tension direct-current system in this country within the next few months.

THE ELECTRICAL UNDERTAKING OF THE BIRMINGHAM TAME AND REA DISTRICT DRAINAGE BOARD.

By L. F. MOUNTFORT, Associate Member.

(*Paper first received November* 22, 1910. *Revised December* 27, 1910. *Read before the* BIRMINGHAM LOCAL SECTION *February* 8, 1911, *and before the* MANCHESTER LOCAL SECTION *February* 28, 1911.)

Works of sewage disposal have probably not been regarded as likely sources of demand for electricity by municipal electrical undertakings in seeking for power consumers. As, however—especially where the bulk of the sewage has to be pumped—the demand for power is quite likely to be from 5 to 10 per cent. of the entire output of the central station, the author hopes that it may prove interesting to members of the Birmingham Local Section of the Institution to hear what has been done in this respect in their own neighbourhood by what is probably the largest undertaking of its kind in the world at the present day. The author, therefore, proposes to describe the electrical undertaking of the Birmingham Tame and Rea District Drainage Board, which is responsible for dealing with and treating the sewage from a population of about 1,000,000 persons in Birmingham and the neighbouring districts.

The present paper is divided into two portions, the first giving a short description of the electrical power transmission scheme installed by the Drainage Board in 1905, and the second describing more particularly the sewage pumping station and plant recently erected at the Nechells Outfall Works, for the purpose of raising large quantities of sewage and storm-water for distribution on the surface of filter beds. The paper concludes with a consideration of the torque requirements of large squirrel-cage induction motors for the direct driving of low-lift centrifugal pumps.

POWER TRANSMISSION SCHEME.

The original scheme of power transmission was installed in order to replace a system of small pumping units consisting of portable steam engines and belt-driven centrifugal pumps, which were required

at a number of points in order to raise sewage to small areas of land above the main gravitation level. These pumps were situated a considerable distance apart, the farthest being about 5 miles from the outfall works at Nechells.

At this time the Corporation of the City of Birmingham had under consideration the erection of a refuse destructor in the Nechells district, and the prospect of obtaining a cheap supply of power induced the Drainage Board to substitute a scheme of electric transmission of energy throughout their estate (about 2,800 acres) in place of the small isolated plants above referred to. A considerable saving (about £600 per annum) in working expenses was anticipated on this account, and, as a matter of fact, has been fully borne out in the results obtained. A preliminary estimate of the amount of power likely to be required showed that an ample supply of steam for all existing purposes could be obtained, and an arrangement was come to between the respective authorities, the Drainage Board obtaining a supply of steam at a purely nominal figure.

Under this arrangement the refuse destructor, boiler house, and generating station were all executed under the same contract, and formed one block of buildings. The method of distribution adopted consisted of a 3-phase 2,250-volt overhead transmission line feeding into sub-stations at various points, where the pressure is reduced to 200 volts by means of static transformers. The destructor cells are "top feed" cells, and are hand-fired. There are eight cells, arranged in two series of four, each series having its own fan, which passes the air through the "air heaters" occupying the space between the two sets of cells.

The boiler plant consists of three 30 ft. by 8 ft. Lancashire boilers, two being gas-fired, and the third arranged for coal firing. The coal-fired boiler was installed to operate the plant during the week-ends when the destructor is shut down.

The generating station equipment consists of two 115-k.w. 2,250-volt 3-phase 428 revs. per minute generators, each coupled to a 175-B.H.P. Belliss high-speed engine. The generating units are self-contained, each being provided with an exciter mounted on an extension of the shaft. From this station the power is distributed by means of an overhead transmission line consisting of hard-drawn copper wire supported on creosoted wood poles by means of triple-shed porcelain insulators. This line crosses the public roadway in four places, and at these points special steel terminal poles are provided, the line being taken underground as a 3-core cable which is led down under the pole and laid solid in bitumen under the roadway. Fig. 1 is a general plan showing the amount and distribution of the loads at various points, those with a double circle being the ones installed in 1906. The total length of the line is 5½ miles, and the copper section was originally proportioned to give a pressure drop of 7½ per cent. over the whole line at maximum load.

The general plan adopted in the sub-stations is to equip each with a

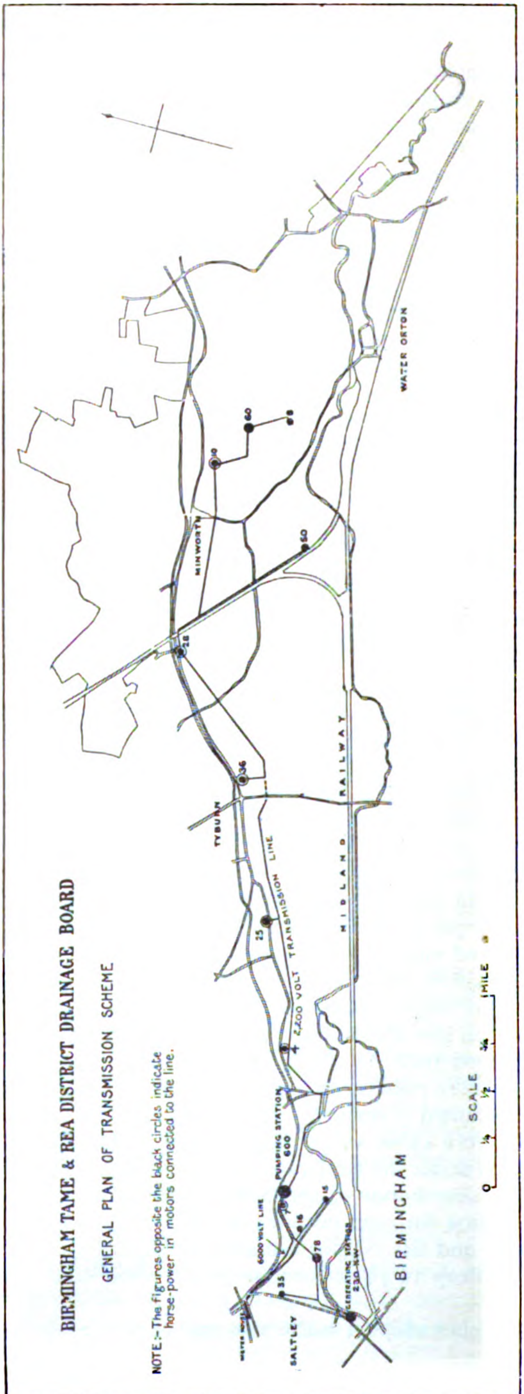

BIRMINGHAM TAME & REA DISTRICT DRAINAGE BOARD
GENERAL PLAN OF TRANSMISSION SCHEME
NOTE:- The figures opposite the black circles indicate horse-power in motors connected to the line.
2,200 VOLT TRANSMISSION LINE
MIDLAND RAILWAY
WATER ORTON
MINWORTH
TYBURN
BIRMINGHAM
SALTLEY
PUMPING STATION 600
SCALE
1 MILE

FIG. I.

separate transforming plant suitable for the output of the motor installed. The stations are divided into two rooms, one containing the transformers and the other the motor and pump. The switch panel is built into the wall dividing the two rooms, the back of the panel being accessible only from the transformer-room. This arrangement was adopted in order to minimise risk of accident due to ignorance or carelessness. At the Saltley and Minworth sub-stations the low-tension distribution is carried outside the station to motors in the vicinity, the average distance being about 300 yards.

As was to be expected, when electrical power had once been installed its use very rapidly increased, and at the present time it has been applied to every process throughout the disposal works requiring mechanical power, and is even used for the milking of cows.

TABLE I.

1906.

Motors connected to Line.

	Horse-power.
Sewage pumping ...	88
Screens and elevators...	15
Workshops and farm...	18
Sewage distributors ...	3
Total	124
Maximum demand on station ...	100 k.w.
Annual load factor	47 %
Diversity factor ...	1·24

1910.

Motors connected to Line.

	Horse-power.
Sewage pumping ...	272
Screens, elevators, penstocks, etc.	30
Gravel and ash washers	30
Workshops and farm ...	18
Sewage distributors ...	10
Total	360
Maximum demand on station ...	150 k.w.
Annual load factor	40 %
Diversity factor ...	2·40

A glance at Table I. showing the horse-power and application of motors connected to the system in 1906 and at the present time, will show clearly the great increase which has taken place. This increase amounts to about 175 per cent., and the existing steam supply is now unequal to the demand made at certain periods of the day. It will be observed that although there has been a great increase in kilowatts connected to the system this has not made a corresponding increase in the maximum demand, which has only increased 50 per cent., the load factor having fallen slightly and the diversity factor being almost doubled. This is accounted for by the fact that most of the motors recently added only work for a short time during the day and that two of the largest of them (viz., 50 B.H.P. each) never require to be used simultaneously.

As it was not practicable to obtain any appreciable increase of power from the destructor, advantage has been taken of obtaining a

bulk supply of electricity from the Aston Corporation mains in connection with the large pumping station recently erected near Bromford, to obtain a standby supply for the existing station, as will be more fully explained in the second portion of the paper.

Fig. 2 gives a typical daily load curve, the hatched portion showing the units supplied from the Corporation main at the peak of the load. Although the demand for a continuous load throughout the twenty-four

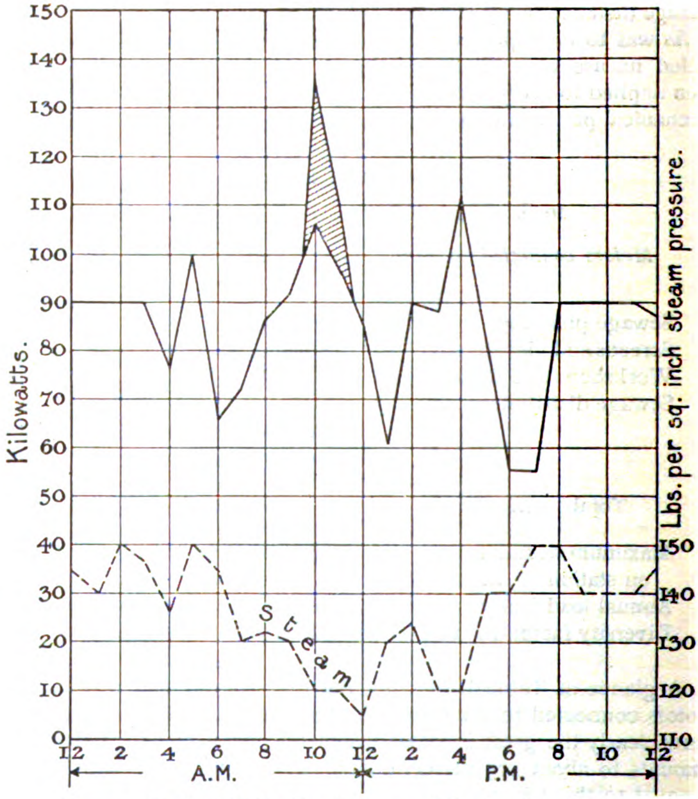


FIG. 2.—Typical Daily Load Curve of Destructor Station.

hours makes the plant very suitable for destructor steam, yet the considerable variation in load throughout the day counterbalances to some extent this advantage, and it is rather unfortunate in this respect that the refuse destructor and electrical generating station are under entirely separate management.

The greater part of the work of sewage disposal requiring power has necessarily to be done during the day, and although every attempt is made to increase the night load and reduce the day load it has not

been found practicable to do this to any appreciable extent. One result of the large increase in demand has been to make the drop in the line somewhat excessive at peak loads, amounting as it does to about 12 per cent. As, however, the peak load rarely occurs when lighting is required this is not so objectionable as might at first sight appear. With the present transmission voltage—viz., 2,250—not much can be done to minimise this, as a large expenditure in increasing the copper section of the line would not have the effect of decreasing the percentage drop in a degree commensurate with the cost. The transformers near the end of the line are now connected up on a tapping giving a slightly smaller ratio of transformation in order that the voltage on the motors shall not fall below the normal rated voltage of the machines.

With reference to the employment of destructor steam for generating power for sewage disposal purposes it may be interesting to observe that the supply and demand naturally bear a constant ratio to one another, as they both depend directly upon the population of the district. The power is mainly required for pumping purposes, and taking the following figures as a basis of calculation, viz.:—

15 cwts. of refuse per 1,000 persons per day;
50 units generated per ton of refuse burnt;
30 gallons per head per day water supply;
50 per cent. overall efficiency for line, motors, and pumps;

we find that the consumption in a destructor of the solid refuse of a district would be sufficient to raise six times the dry weather flow of the sewage or liquid refuse to a height of about 30 ft.

The requirements might be said to be fairly average ones for works where the whole of the sewage has to be pumped, and it would therefore appear that the supply and demand are fairly well suited to one another. It must not be overlooked, however, that this is only as regards the probable maximum demand, and that the general load factor of such a plant would by no means be a good one.

As regards the cost and working expenses of the present plant, the conditions are somewhat peculiar. Only a nominal sum per annum is charged for the destructor steam, and it may be said that practically the whole expenses are the standing charges covering interest and depreciation on cost of installation, maintenance, and wages of staff. Under these conditions, of course, the cost per unit of output is almost in exact inverse proportion to the load factor. At unity load factor this amounts to about 0·35d. per unit generated. The average annual load factor of the plant is about 40 per cent., making the actual cost about 0·875d. The average power factor of the whole system is about 0·85. Practically no trouble whatever has been experienced in the system since its installation five years ago.

Before passing to the second portion of the paper, it may perhaps be of interest to consider some of the various processes occurring in

sewage disposal works to which electric power may be suitably employed. The largest demand for power will, of course, always be associated with those plants where all or any portion of the sewage has to be pumped either at the commencement or at any subsequent stage of the process; but as the present paper is mainly devoted to sewage pumping plant nothing further need be said here on this point. There are, however, other mechanical processes requiring power which are more or less to be found in all sewage disposal works, and some of these are here briefly described.

Screening and Dredging Apparatus.—The first operation is usually to provide means of arresting the heavy solid matter, sand, rags, paper, etc., which are brought down with the sewage, and for this purpose suitable screening and dredging plant is necessary. The latest type of plant of this kind for large works consists of a travelling bucket elevator running on rails over the centre of a large deep and narrow channel into which the sewage first enters on arriving at the outfall works. The channel is usually about 14 to 16 ft. in width at the top, and the lower portion is gradually tapered down until there is just room for the dredger buckets to pass between the walls. The arm carrying the buckets is about 40 ft. long, and is supported on a four-wheeled truck running above the centre of the pit. The buckets are carried on endless chains passing around top and bottom drums, and deliver the material at the top end into a chute which discharges into a wagon trailed behind the dredger. The bucket arm is supported on trunnions at about one-third of its length from the top, and can be raised into a horizontal position clear of the pit for inspection or repairs. All the operations are performed by means of a single motor of about 15 B.H.P., which collects current from wires slung alongside the pit. The bucket speed is generally about 60 ft. per minute, and the traversing speed 15 ft. per minute.

Lime Mixers.—In some works it is found advisable to precipitate the sewage chemically in order to obtain the best results, and for this purpose lime is frequently used as a precipitant and is added to the sewage in the form of milk of lime. There are several forms of lime mixers, one of the simplest and best being of the following description: A circular cast-iron tank, about 8 to 10 ft. in diameter and about 6 ft. deep, is provided with a central vertical spindle, carrying a cone-shaped spreader which is rotated at a speed of about 40 revs. per minute. The cone is open at the top and bottom, the diameter being respectively about 2 ft. and 4 ft., and the axial depth about 2 ft. The cone is provided with projecting ribs on the inside face, and the rotation sets up a forced vortex, causing a continuous circulation of the liquid from the centre towards the sides, the motion being downwards through the centre of the cone and upwards at the side of the tank. The lump lime is tipped into the tanks over the centre and falls through the opening in the top of the cone, being then quickly broken up and sent into solution. Several of these mixers can be driven from one motor by means of a horizontal shaft along the centre of the tanks, driving the

vertical spindles through worm-gearing. A motor of about 8 B.H.P. is sufficient for two mixers of the size mentioned.

Sludge Pressing Machinery.—The solid matter which is deposited in the form of sludge in the tanks is in some cases disposed of by being pressed into what is known as sludge cake, in which form it can be easily carted away and disposed of without nuisance. The liquid sludge is run into receivers, from which it is forced into the presses by means of compressed air at a pressure of about 60 lbs. per square inch. These presses consist of a number of corrugated plates, between each of which is inserted a press cloth. The plates are firmly clamped together in a horizontal row, and the sludge is then forced in through a central pipe, the pressure gradually increasing as the press fills up. The bulk of the water in the sludge is forced through the cloths and drains away, leaving behind the sludge cake, which is then removed and carted to a tip. By this means the sludge is reduced to about one-fifth of its original bulk. The power required for the air-compressing plant will vary from about 10 to 50 B.H.P. according to requirements.

Sewage Distributors.—Mechanical distributors, as distinct from spray jets, are largely used for distributing the clarified tank effluent over the surface of the filters, which generally constitute the final stages of the purification process. These distributors may be either of the revolving circular type—in which case the filter beds are made circular—or they may be of the rectangular travelling description which have the advantage of being more economical in ground space. Both types consist, approximately speaking, of a cast-iron trough or pipe perforated with a number of small holes, through which the liquid issues in fine streams. In the circular type the trough revolves about a central feed pipe and in the rectangular type is propelled backwards and forwards over the area of the filter, being supported at either end on light rails. These distributors take very little power to operate them, and for this reason are nearly always self-propelled under the head of sewage. Instances are to be found, however, where both types have been electrically driven and two circular distributors at the Drainage Board's Works are driven by small electric motors.

From the foregoing brief description it will be seen that the incidental power required for various purposes, apart from pumping, may in large works amount to 100 B.H.P., and the load factor will as a rule be a fairly good one.

Sewage Pumping Station.

In the second portion of the paper the author proposes to describe the electrical pumping plant recently installed by the Drainage Board at their works at Nechells for the pumping of sewage and storm-water, giving at the same time the reasons for the choice of the various types of apparatus employed, and to discuss some of the electrical and mechanical problems which arise in dealing with plant of this description.

The new pumping station was installed for the purpose of dealing principally with the large excess flows brought down by the main outfall sewers in time of rainfall, and when completed will contain plant of a capacity of about 1,000 H.P. The sewage is lifted and distributed over a large area of bacterial filters immediately to the south of the station.

These filters consist chiefly of screened and washed gas works ashes, of a size varying from ¾ in. to about 3 in. in diameter, which are laid to a depth of about 6 ft. on a cement concrete floor. The sewage, after settlement in a large basin holding about 13,000,000 gallons, is distributed over the surface of the filtering material and slowly percolates through to the floor underneath, from which it is led away by means of a system of drainage tiles to the effluent channel. The method of distributing the sewage on the surface of the filters consists in forcing it under pressure through a large number of nozzles or jets so that the entire surface of the filters is covered with a fine spray. A network of distributing pipes is laid on the surface, each pipe being 4 in. in diameter and provided with small brass nozzles $\frac{5}{16}$ in. in diameter, spaced 6 ft. apart. A small cone or splasher is supported over these holes against which the jet impinges, and is spread out over a circular area of a diameter approximately twice the head on the orifice. By arranging the spacing of the jets so that there is a certain amount of overlapping, the whole area of the filter can be covered.

There are at present 16 acres of filters at work, and the ultimate area provided for is 30 acres, upon which it is intended to deal with excess flows of sewage storm-water at a maximum rate of 100,000,000 gallons per day. The whole area is divided into sections of 2 acres each, which can be fed independently, and each acre requires about 600 jets. The watering of these filters is controlled by a system of electrically operated sluice valves, as will be explained later, so that the area in work can be adapted to meet the varying rate of flow from hour to hour. The level of the surface of the filters is about 10 ft. above the general gravitational level, so that it has been necessary to instal pumping machinery, the total lift including the head on the jets being about 19 ft.

Nature of Load and Load Factor.—The nature of the load to be dealt with and the probable load factor of the plant is naturally the first consideration in determining the type of plant to instal, and the author therefore proposes to deal first with this point.

The rate of flow of sewage during dry weather varies regularly from hour to hour during the day. The maximum rate is equal to about 1·5 times the mean and occurs about midday, while the minimum rate, equal to about half the mean rate, occurs during the early morning.

The flow above referred to is what is known as the "dry weather flow" (d.w.f.) and is that due to the ordinary domestic sewage, together with a certain amount of manufacturing trades waste. The amount of the flow is ordinarily dependent only upon the water supply of the

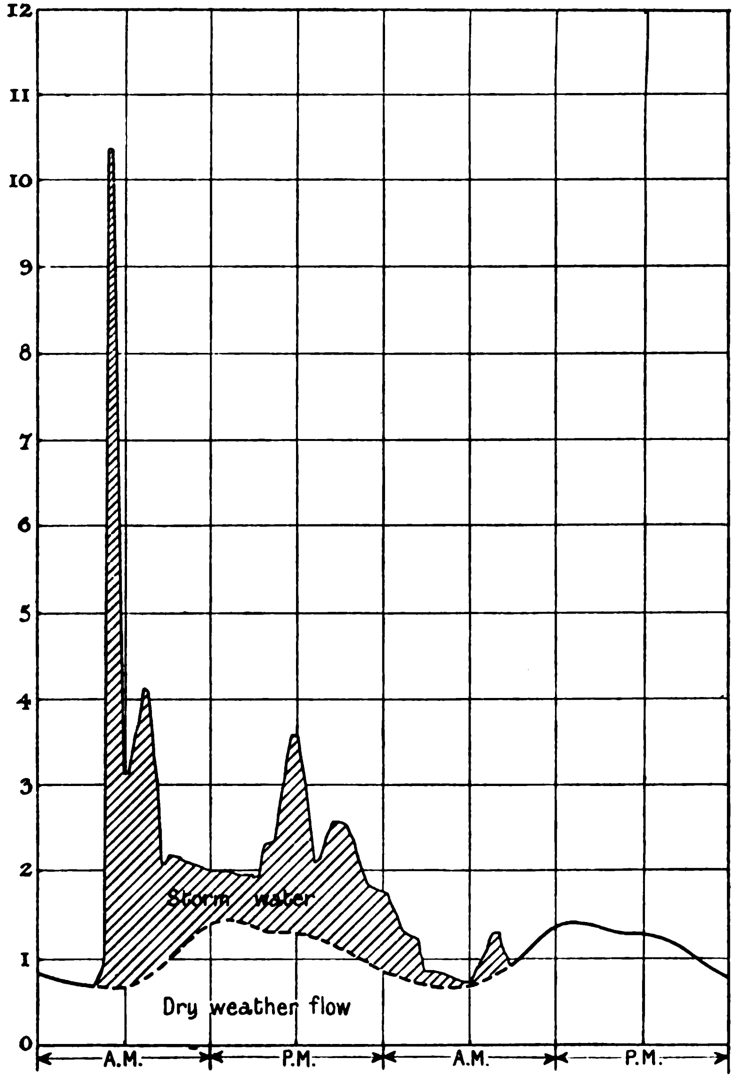


FIG. 3.—Diagram showing Effect of Storm Water on Flow of Sewage.

Ordinates denote value of ratio $\frac{\text{rate of flow}}{\text{mean rate of flow in dry weather}}$.

district, and in the absence of rainfall would remain fairly constant in amount and in degree of fluctuation from day to day. In times of rainfall, however, this flow is subject to large and sudden variations, the magnitude of which depends upon the size and configuration of the district, the extent to which separate storm sewers are provided and the number and effectiveness of the storm overflows on the branch sewers. At the Outfall Works at Nechells, a rate of flow of 10 to 12 times the normal "dry weather flow" has been measured, and for a short time a rate of flow of 150 times the normal has been measured in an individual sewer in the City. Fig. 3 shows a typical diagram recorded during storm time, the shaded portion being the extra quantity due to rainfall. Fig. 4 is a diagram showing the mean value of the abscissæ taken from records similar to Fig. 3, and representing an average for the year 1908; as before, the shaded portion indicates extra flow due to rainfall, and it will be at once evident that although the rate of flow is very largely increased, the total extra quantity to be dealt with is small compared with the normal daily quantity. The black portion of the shaded area represents that portion of the flow which the present pumping station is constructed to deal with.

In sewage engineering it is customary to consider the total rate of flow in terms of the mean rate of flow in dry weather, and in this connection a word of explanation will be necessary. For instance, it is customary to speak of certain portions of the plant dealing with so many "dry weather flows"; this, of course, does not mean that a quantity equal to so many times the normal daily quantity is to be dealt with, as it will be at once evident from the diagram (Fig. 4) that the total quantity arriving at the works cannot be greatly in excess of the quantity due to the "dry weather flow" only. What is meant is that a particular portion of the plant deals with everything up to a rate of flow equal to so many times the normal rate. The annual load factor of a pumping plant to deal with sewage will, therefore, depend entirely upon the limits of flow between which it has to work, and may vary from almost 100 per cent. to 3 per cent. or less.

Table II. gives approximate values of the load factor for plants working between various limits of flow, the figures being obtained from the diagram (Fig. 4). In the case of the present pumping station the requirements were that it should deal with a maximum rate of flow of 70,000 gallons per minute, commencing at a rate of about 1½ times the normal "dry weather flow," this portion being, as before mentioned, indicated by the black portion of Fig. 4. The annual load factor in this case is about 3·5 per cent. for the whole plant.

Under these circumstances the question of a high efficiency becomes of small importance compared with that of low first cost, and pumping machinery of the ordinary centrifugal type was decided upon.

One of the chief requisites of a plant for dealing with large excess flows of sewage is that it shall be capable of being started up at short notice, and the whole plant got to work with the minimum of delay.

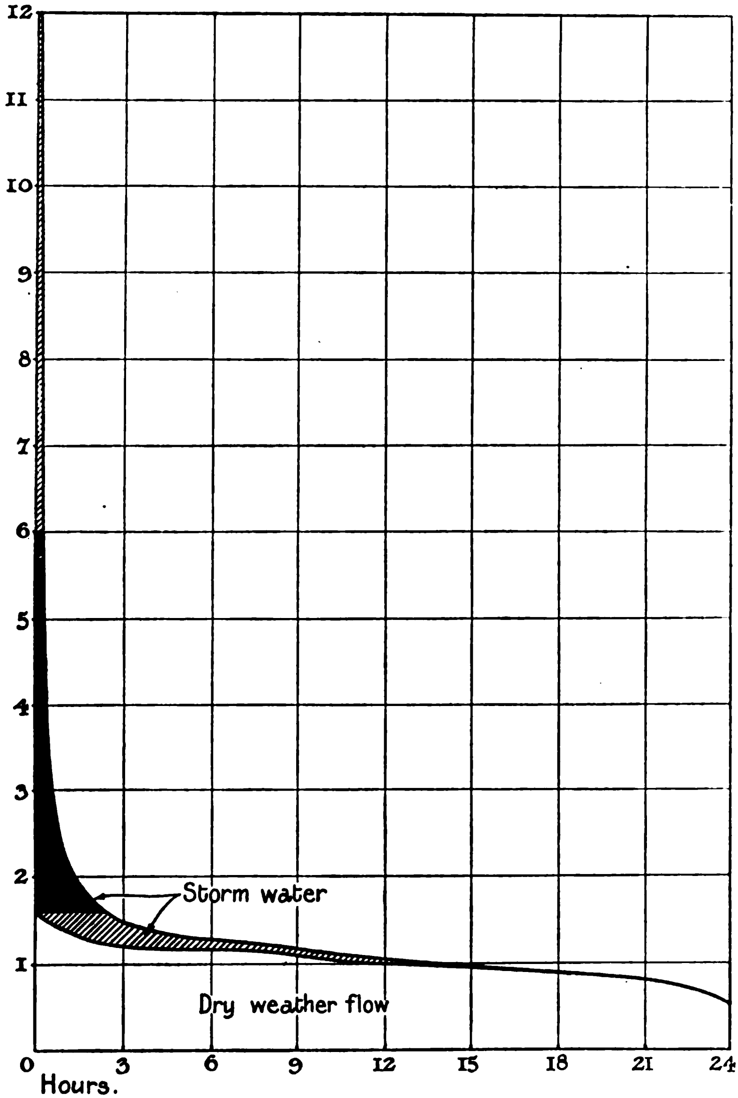


FIG. 4.—Diagram showing Mean Value of Abscissæ of Total Flow.

Ordinates denote value of ratio $\frac{\text{rate of flow}}{\text{mean rate of flow in dry weather}}$.

For this reason it was necessary to have a supply of power which could be called upon to the full amount required whenever necessary, and in this connection the relative merits of gas and electric driving were fully considered. As the figures may be of interest, these are given in Table III., which forms a comparative estimate of the cost of both schemes. It will be seen from the table that from the point of view of cost there was little to choose between the two schemes. The advantage of the electrical scheme, however, was that it was possible by installing a static transforming plant to provide at a minimum outlay a standby for the existing generating plant, where the demand was already showing signs of exceeding all previous estimates made when the station was first put down.

Table II.

Load Factors of Sewage Pumping Plant.

Values of $\frac{\text{Maximum Rate of Pumping}}{\text{Mean Rate of Flow in Dry Weather}}$.	Values of $\frac{\text{Rate of Flow at which Pumping commences}}{\text{Mean Rate of Flow in Dry Weather}}$. 0	1	2	3	4	5
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
1	93	—	—	—	—	—
2	56	20·0	—	—	—	—
3	39	12·0	4·0	—	—	—
4	30	8·7	3·0	2·0	—	—
5	24	6·9	2·5	1·8	1·6	—
6	20	5·8	2·2	1·6	1·5	1·3

The supply of electricity obtained from the Corporation mains is 3-phase 50-period current at a pressure of about 6,000 volts, and is brought at this voltage into the pumping station. The point of junction of the Drainage Board feeder with the main is the Lichfield Road, near Salford Bridge, the current being metered at this point, where there is also a main feeder switch by which the whole supply can be cut off. From this point, which is about 1,400 yards from the pumping station, an 0·1 3-core paper insulated lead-covered cable is laid across and alongside the River Tame for a distance of about 450 yards. The cable is provided with a Board of Trade galvanised wire earth-shield over the lead and is laid solid throughout in stoneware troughing filled in with bitumen and covered with flat tiles. The cable is laid about 3 ft. under the bed of the river where it crosses, and about

2 ft. deep in the ground alongside the Birmingham and Fazeley Canal. For the remaining 950 yards to the pumping station the overhead type of construction is adopted, the whole of this being erected on land belonging to the Drainage Board. The cable terminates in a switch house containing an oil-break switch, by means of which the cable may be disconnected from the overhead line.

Near the switch house is erected a hollow steel terminal pole, three single-core lead-covered cables being taken up inside the pole and terminating in a circular steel hood above; the ends are bent outward and taped up, the bare wires passing out through the bottom of the

TABLE III.

Comparative Cost of Gas and Electricity.

	Gas Plant.			Electric Plant.		
Capital Cost.	£	s.	d.	£	s.	d.
Transmission line	—			900	0	0
Gas main	1,100	0	0	—		
Machinery	5,000	0	0	5,000	0	0
Buildings and foundations...	7,000	0	0	5,500	0	0
Hydraulic mains and valves	2,000	0	0	2,000	0	0
Total	15,100	0	0	13,400	0	0
Annual Cost.						
Interest and depreciation at 8 per cent.	1,208	0	0	1,072	0	0
Working Expenses (based on an assumed annual demand of 120,000 W.H.P.-hours per annum).						
5,000,000 cub. ft. of gas at 1s. 7d.	395	16	8	—		
180,000 units at 1d.... ...	—			750	0	0
Wages	600	0	0	600	0	0
Repairs, oil, waste, and stores	120	0	0	25	0	0
Total	2,323	16	8	2,447	0	0

hood through long porcelain insulators. The hood is then filled up solid with box compound. Three horn-type lightning arresters are fixed on brackets at the top of the pole, and choke coils consisting of about ten turns of the line wire are inserted between the line and the cables. The steel pole is surrounded on three sides and on top by a protecting network or screen of expanded metal erected on wood poles. The horn arresters were at first connected directly to earth without any resistance in the earth circuit. Considerable trouble was, however, experienced, especially when the line was lightly loaded, the

whole system being frequently shut down due to the arresters flashing over for no apparent reason. It was therefore decided to put special graphite resistances of about 500 ohms each in each lag of the earth circuit. Trouble was also experienced due to snow lodging between the horns, and the whole terminal pole has now been covered over with a screen of expanded metal. Since then no trouble in the nature of shutdowns has been experienced. In the author's opinion, 6,000 volts is too low a pressure for the satisfactory employment of horn arresters when located in an exposed position, as the gap has to be so small that it is difficult to ensure its being kept free.

The overhead pole line construction is of the usual type, with single creosoted wooden poles spaced about 50 yards apart, and carrying brackets and insulators for supporting the line wires. These consist of three hard-drawn copper wires arranged two on one side of the pole and one on the other, the distance between the wires being about 3 ft. in all directions. A barbed wire aerial earth is strung across the tops of the poles, and is earthed at three points of the route by means of copper earth-plates. The route length is about 750 yards, and for the latter half of the distance the line runs alongside the Board's existing power line, and at a distance from it of about 4 yards. At the inlet to the pumping station the line passes through a rectangular aperture into a small room at the top of the building, in which are fixed the lightning arresters, choke coils, etc. The branch connection to the existing 2,250-volt line also enters the building at this point. From here single lead-covered cables pass down through the floor to the main feeder switches in the switch gallery below.

The Pumping Station.—The pumping station (see Figs. 5, 6) is 120 ft. long and about 40 ft. in width, and constructed of brindle bricks with buff facings. The main entrance is at the west end, the entrance floor overlooking the pump-room, which occupies the main portion of the building. On the south side, and running the whole length of the pump-room, is the operating gallery, in which is placed the whole of the switchgear and controlling apparatus for the main pump valves, compressed air valves, etc., as well as a rotary air compressor for charging the pumps. Above the operating gallery is a flat roof on which is placed the small lightning-arrester room previously referred to. Underneath the operating gallery are the valve-rooms, transformer-room, the oil store, heating chamber, and boot-room, the last mentioned being for the use of the men engaged in looking after the filter beds, and having a separate entrance from the front of the building.

The pump well is constructed outside the building on the north side, and extends the whole length of the pump-room. The main inlet to the well is from a 7-ft. diameter culvert at one end, and at the other end from a rectangular penstock connecting to the existing 8-ft. conduit. The inlets to the pump suction pipes are rectangular apertures in the vertical wall dividing the well from the basement floor inside the building, and are formed of stone blocks well rounded to minimise entrance loss. The area of these openings is about 1·5 times

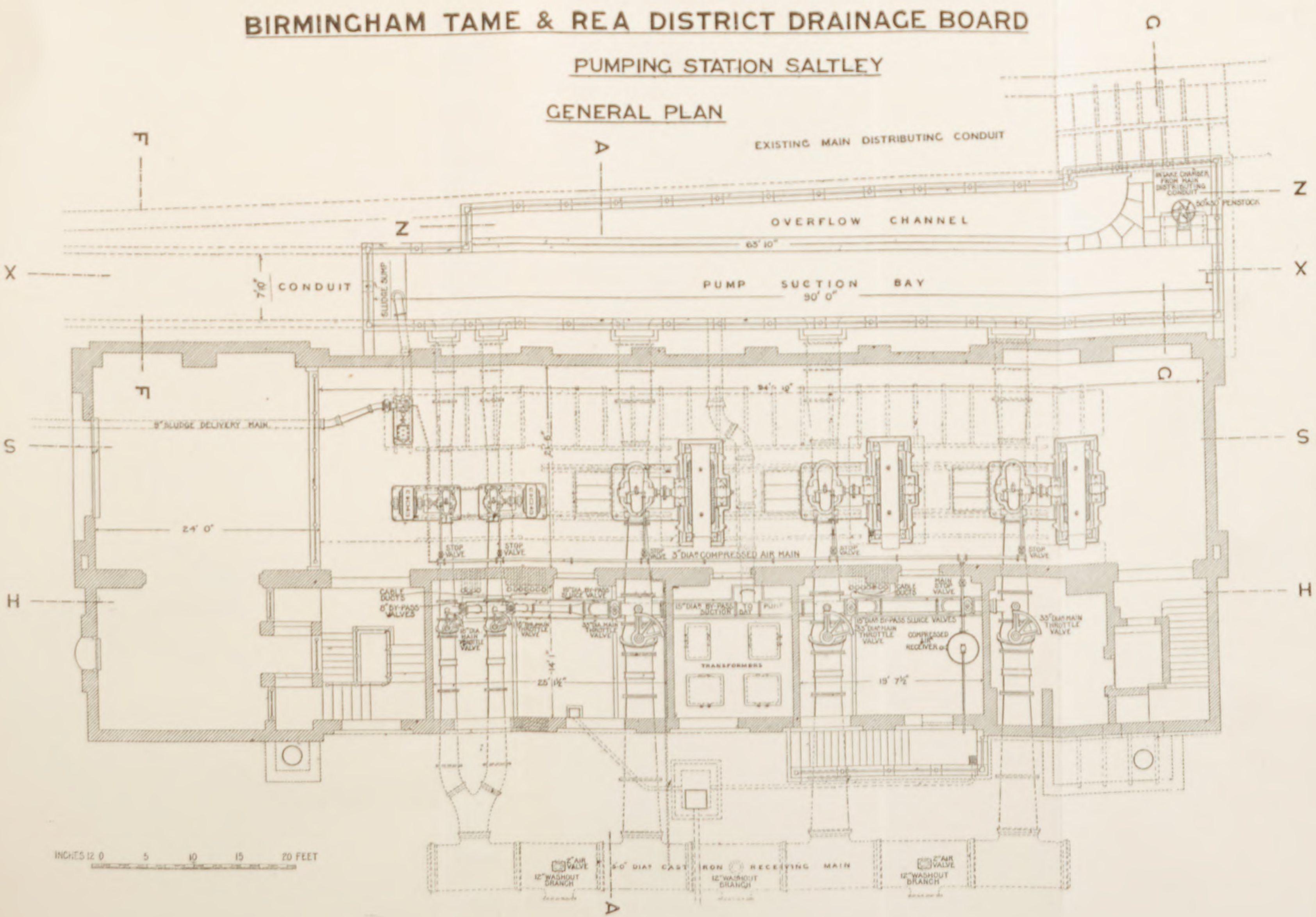
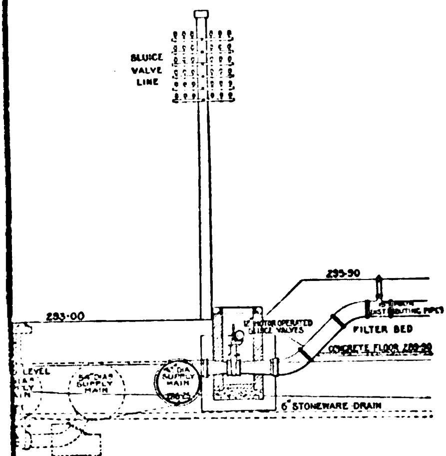

BIRMINGHAM TAME & REA DISTRICT DRAINAGE BOARD
PUMPING STATION SALTLEY
GENERAL PLAN
EXISTING MAIN DISTRIBUTING CONDUIT
OVERFLOW CHANNEL
63' 10"
CONDUIT
7' 0"
PUMP SUCTION BAY
90' 0"
SLUDGE SUMP
8" SLUDGE DELIVERY MAIN
24' 0"
94' 10"
STOP VALVE
3" DIA. COMPRESSED AIR MAIN
CABLE DUCTS
8" BY-PASS VALVES
TRANSFORMERS
25' 11½"
19' 7½"
33" DIA. MAIN THROTTLE VALVE
15" DIA. BY-PASS SLUICE VALVES
COMPRESSED AIR RECEIVER
MAIN STOP VALVE
50"x50" PENSTOCK
INTAKE CHAMBER FROM MAIN DISTRIBUTING CONDUIT
2" AIR VALVE
12" WASHOUT BRANCH
5'-0" DIA. CAST IRON RECEIVING MAIN
INCHES 12 0 5 10 15 20 FEET
A
C
F
X
Z
S
H

FIG. 5.

on-
ınd
ge-
'ith
vas
' to
ion
on,
ell,
ith



ıg
:h
ər
g
ıo
ıs
g
h
e

ıf
e
ə
s
:

the area of the suction branches on the pump, to which they are connected by means of horizontal pipes of gradually tapering section and quadrant bends. This, of course, does not form such an ideal arrangement as that of having the suction well underneath the pumps with short lengths of vertical section, but as the maximum water-level was about 2 ft. above the level of the pump-room floor, it was necessary to keep the pump well outside the building altogether. The suction pipes are not provided with foot valves or strainers of any description, as the sewage is well settled in large tanks before entering the well, and the pumps can be primed by means of ejectors working with compressed air.

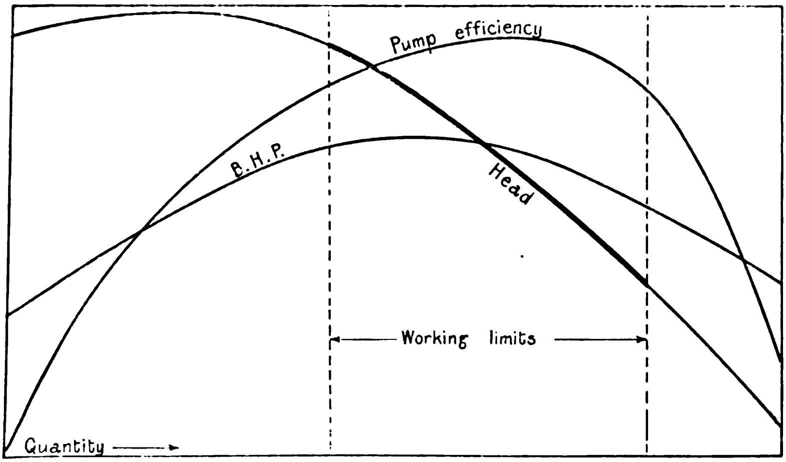


FIG. 7.—Diagram showing Characteristic Curves of Centrifugal Pump with Backward Curved Vanes.

Pumping Units.—As already stated, the maximum rate of pumping is 70,000 gallons per minute, and the ultimate area of filters to deal with this quantity will be 30 acres, giving about 2,350 gallons per acre per minute. As will be seen presently, the pumps are capable of working down to about half-load without appreciable sacrifice of efficiency, so that the smallest unit is designed for a normal output of 4,700 gallons per minute, and two sets of this capacity are installed. The remaining portion of the load will be divided between three large units, each having a normal rating of 20,200 gallons per minute, and two of these are already laid down.

Special Type of Pump.—The sewage is distributed over the surface of the filters through numerous small nozzles, or sprays, which spread the water more or less uniformly over the surface area, the pressure at the nozzles being about 7 ft. The pumps deliver direct into the mains which feed the filters, and as the pressure on the nozzles forms about

one-third of the total head against which the pumps are working the special relations of volume and pressure which are characteristic of centrifugal pumping machinery are brought strongly into prominence. Fig. 7 shows approximately the general characteristic curves of head and volume for ordinary centrifugal pumps, from which it will be noticed that any variation in discharge over the best portion of the efficiency curve is accompanied by an appreciable variation in pressure. One of the conditions of distributing sewage over a filter is that the rate of distribution shall remain fairly constant over the whole area covered, and this, of course, means, with a given size of nozzle, that the pressure must remain as nearly as possible constant whatever volume is being delivered. In Fig. 8 is shown a diagram giving a rough idea of the general arrangement on the delivery side of the pumps, and it will be evident that, with the pump working at constant speed, if part of the area be cut off by closing any of the valves at B, the pressure on the remaining portion would immediately rise to an extent determined by

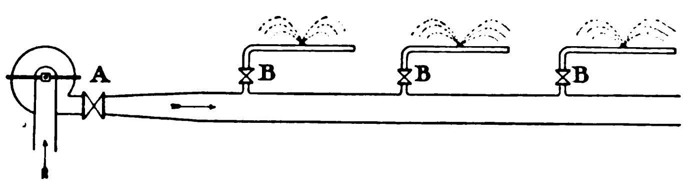


FIG. 8.—Diagram showing General Arrangement of Mains and Valves on Delivery Side of Pumps.

the characteristic of the pump and the proportion of the total head consumed by the nozzles. In the present instance this would probably have amounted to a maximum of about twice the normal pressure, with a corresponding increase of about 40 per cent. in the rate of distribution. This pressure could, of course, be reduced by either closing the main valve at A or by reducing the speed of the pump. Either of these two methods would, however, be attended with a great reduction in efficiency of operation. By the first method the surplus head would merely be wasted in forcing the water through the partially closed valve, the input to the pump remaining about the same. In the second case we have not only to consider the efficiency of the pump itself, which would not be appreciably affected, but also that of the motor, and this being of the induction type any method of speed variation giving a close range would be attended with as great a reduction of efficiency as in the former method, the only difference being that the power which is wasted in hydraulic resistance in the first case is wasted in electrical resistance in the second. It was therefore desirable to obtain a form of pump which would give a very flat pressure curve over the best range of efficiency, and it was pointed out by the author that this could be obtained by making the vanes of the pump disc radial at the outlet angle, instead of with a large backward curvature,

as in the usual type. Fig. 9 shows the characteristic curves of this pump, and is plotted from observations during an actual test of one of the pumps after about six months' working; it will be seen that there is a variation of only about 15 per cent. in the pressure between full and half load, and this also corresponds approximately to the best portion of the efficiency curve. It may be stated that this particular form of vane is by no means new, and was, as a matter of fact, about the earliest type to be adopted; but it happens to possess certain disadvantages for general working, and was more or less abandoned for the usual type of disc with backward curved vanes. In the present instance, however, the conditions of working are eminently suited to this type of pump, and the results obtained have fully justified its

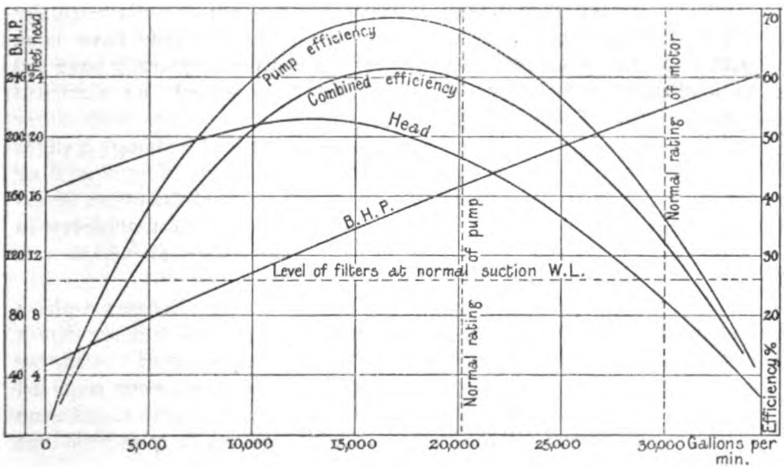


Fig. 9.—Characteristic Curves of $\frac{28}{32}$-in. Centrifugal Pump and 225-B.H.P. Induction Motor.

adoption. This type of pump discharges at a high velocity, and in order to obtain a good efficiency must be provided with a gradually expanding discharge pipe, in which the velocity head is converted into pressure. Under these circumstances the overall efficiency of the pump and discharge pipe may be as much as 70 per cent. (see Fig. 9). As an example of what can be effected by this means, it may be mentioned that in the case of the present pumps about 27 per cent. of the total lift is obtained between the pump outlet and the end of the expanding pipe. Incidentally, it may be noted that this expanding discharge pipe may be taken advantage of to gauge the quantity of water being pumped, on the principle of the Venturi meter. This has been done in the present case, and differential mercurial pressure gauges have been installed with one leg connected to each end of the expanding delivery pipe. These gauges have been calibrated

against a direct tank measurement, the tank holding about 5,000,000 gallons, and the quantity can be determined with an estimated accuracy of within 1 per cent. error.

It has been necessary to enter at some length into a description of the pumping portion of the plant before proceeding to the details of the electrical equipment, as these latter have been determined largely by the hydraulic requirements, and it is desired to show why it has been necessary to install machines of a somewhat abnormal type for driving the pumps.

The total lift is only 19 ft. at normal suction level, and as one of the characteristics of the type of pump chosen is that for a given head and output, it requires to run at a slower speed than the ordinary type, the choice of slow-speed motors was a necessity, and the actual speed specified in each case was a compromise between two diametrically opposed requirements. A slower speed would certainly have been better for the pump, while a higher speed would naturally have led to a cheaper and better design of motor as regards its electrical performance. The question of using high-speed motors with either reduction gearing or rope drives was considered, and although a slight saving in cost might have been effected, the necessity of greater floor space on the one hand, and simplicity of operation on the other, determined the author to adopt direct-coupled slow-speed machinery in spite of a slightly lower efficiency, the importance of which was minimised by the very small annual demand.

Motors.—The motors driving the pumps are in all cases 3-phase 50-period induction motors with squirrel-cage rotors, and are direct coupled to their respective pumps. The full-load rating of the motors is in all cases fixed about 33 per cent. in excess of the power required by the pumps at normal output, the reason being that with radial vane pumps the power required increases rapidly with any drop in head (see Fig. 9), and this rating was chosen so that if for any reason the pressure should drop to the level of the surface of the filters the machines would not be overloaded. The smaller machines are each of 55-B.H.P. full-load output when running at a speed of 360 revs. per minute, and are wound for operating on a line voltage of 2,200. The large motors are each of 225-B.H.P. full-load output when running at a speed of 194 revs. per minute, and are wound for operating on a line voltage of 6,000. Some particulars of the design are given below:—

Number of stator poles	30
Diameter of rotor	72 in.
Radial depth of air-gap	0·06 "

Stator.

Slots per pole per phase	5
Number of conductors per slot	18
Size of conductors	0·109 in.

Rotor.

Number of slots	459
Conductors per slot	1
Size of conductor	0·7 × 0·26 in.

Power Factor.

Full load	0·84
Three-quarter load	0·80
Half load	0·70

Efficiency.

Full load	0·90
Three-quarter load	0·89
Half load	0·87

The stator slot windings are arranged in a single layer per slot, which reduces to a minimum the likelihood of a breakdown between turns—an important consideration in high-voltage squirrel-cage machines such as the present. In addition to this, the end coils of the winding are specially insulated for the purpose of withstanding any momentary pressure rise at starting.

In the first of the large motors installed the end-rings of the motor were divided up on either side, there being half as many sections as poles. This was done in order to improve the starting torque of the machine. It was found, however, that this caused periodical fluctuations in the rotor currents, which were distinctly noticeable in the noise made by the motor when running, and at the same time caused all the instruments in work to swing, so that it was impossible to get an accurate reading. This was most noticeable in the case of the power-factor meter, which had to be disconnected to prevent it being damaged. The periodicity varied with the slip of the motor, and was equal to the frequency of the supply multiplied by the slip of the motor, or in this case about 90 per minute. The second motor was on this account provided with continuous end-rings, and as it was found that the starting torque of the machine was not appreciably affected, the first machine was dismantled and continuous end-rings substituted for the divided ones.

Starting-gear.—The starting-gear for the motors consists of auto-transformers and oil switches mounted in the operating gallery close to the main water and air valve pillars, the whole of the starting-gear for each pumping set being close to the hand of the operator. The motors are started up on 50 per cent. of the normal supply voltage. For the first of the large motors an ordinary auto-transformer with self-contained oil switch mounted in a cast-iron tank was installed, and although this has so far been quite satisfactory, a somewhat special type of starter has been installed for the second motor. The gear consists of a drum-type switch mounted in a separate tank, two auto-transformers and two choke coils also in separate oil tanks. The choke

coils are inserted between the "starting" and "running" position, so that there is no break in the circuit during the change-over, and are cut out before the running position is fully reached, the whole operation being performed by a single movement of the switch handle.

Switchgear.—The whole of the switchgear is mounted in the operating gallery, and consists of a white marble panel board about 26 ft. long. The general arrangement can be seen from the plan and cross-section of the station (Figs. 5 and 6). The 6,000-volt busbars, isolating links, and oil switches are mounted in fireproof cells behind the board, the operating fronts only being mounted on the panels. The 2,000-volt busbars are in two sections, one set being supplied from the 6,000-volt mains through stepdown transformers, and the other set from the Drainage Board power station. A triple-pole oil switch connects the two sets of bars, and is mounted on the synchronising panel.

During week-ends, when the destructor steam is not available, the existing station is shut down, and the supply taken from the 6,000-volt feeder. The synchronising gear is used for paralleling the two supplies in order to change over without the necessity of interrupting the supply. The 6,000-volt supply is also used to help the existing station during times of heavy load, or when steam is low, and it is of interest to observe that no difficulty has been experienced in running the two supplies in parallel for hours at a time. The actual synchronising of the two systems has never given any trouble, and no undesirable surging has taken place even when the paralleling switch has not been closed at precisely the right moment. It is probable that the length of transmission line and cable between the two stations has the effect of damping any surges that may occur due to faulty paralleling. The advantage of having two sets of 2,200-volt busbars is that, if necessary, one small pumping set can be operated from each supply, without the necessity of running in parallel.

Transforming Plant.—The transforming plant consists of 3 single-phase oil-cooled transformers each of 100-k.v.a. capacity, with a ratio of 6,000 to 2,200 volts, and one 30-k.v.a. 3-phase transformer with a ratio of 2,200 volts to 200 volts. These are installed in a room immediately beneath the switchboard, the three large transformers being mesh-connected and operated by a single oil switch on either side. The 200-volt supply is used for working the compressor motor, sludge-pump motor, sluice-valve motors for the filter beds, and the station lighting.

Delivery Mains and Valves.—The delivery branch from each pump is fitted with a gradually expanding discharge pipe with the object, as already explained, of converting the velocity head of discharge into pressure head, and at the end of each discharge pipe is placed the main controlling valve. These valves are of the "throttle" or "butterfly" type, and are controlled by hand from the operating gallery through suitable gearing. The smaller valves are 18 in. in diameter, and the larger ones 33 in. in diameter. This type of

valve was chosen because of the ease and rapidity with which it can be opened or closed. Had the 33-in. valves been of the ordinary sluice-valve type they would have required about 15 minutes each to open by hand, which would have meant unnecessary delay in getting the plant working, where rapidity of operation was of great importance. The valves in question can be opened in about 20 seconds, and are considerably cheaper than motor-operated sluice valves. A disadvantage of this type of valve is that it is not absolutely watertight when shut, but in the present case this was not detrimental to their use, and no difficulty has been experienced in exhausting the pumps and piping when priming. A byepass pipe is provided connecting up the delivery pipe from the pumps and discharging back into the pump well. The object of this is to assist the pumps in starting against full pressure, such as would be the case when bringing up another pump on to the pipe range when already under working pressure. This will be made clear by reference to Fig. 9, where it will be seen that the pressure running with a closed pump is less than the normal pressure.

Motor-operated Sluice Valves.—In order to facilitate the operation of opening up the filter beds, and bearing in mind that when the scheme is complete it will be necessary to open thirty 12-in. sluice valves in order to bring the whole plant into use, it was decided that these valves should be electrically operated from the pumping station, and for this purpose an overhead pole-line has been erected alongside the valves for supplying current to the small driving motors. The line consists of hard-drawn copper wires, there being six wires to each pair of motors, which are worked two in parallel. Each sluice valve has a small ½-H.P. 3-phase totally enclosed motor mounted on a bracket and operating through spurwheel and worm-gearing, the time taken to open or shut the valve being about 2 minutes. The valves are installed two together in brick chambers with air-tight covers, and a pole is erected close to each chamber, down which the tappings from the overhead line are taken, these consisting of V.I.R. cable in galvanised steel conduit. Two triple-pole double-throw switches are provided in each motor circuit, one being mounted on the switchboard panel at the station and the other acting as a limit switch and being fixed on the sluice valve. The function of the limit switches is to break the circuit when the valve has reached the top or bottom of its travel, and at the same time to leave the motor connected up to run in the opposite direction when the switch at the station is thrown over. These switches are operated by a travelling nut actuated by the gearing on the valve, and a considerable amount of difficulty was experienced at first in obtaining a suitable switch for the purpose. The difficulty arose mainly owing to the fact that two motors being worked in parallel, it was impossible to ensure that both motors should cut out at precisely the same moment, and with the first type of switch employed the motor on the valve which first reached the end of its travel remained short-circuited on the line until the second motor was cut out, owing to the current feeding back and making alive the

forward terminal of the first motor. A type of quick-break switch has now been adopted which gets over the above difficulty, but the arrangement is not yet entirely satisfactory, although the system has been in operation for about 18 months. A new type of valve-gear and switch is now being experimented with, which, it is hoped, will prove entirely successful. This part of the scheme which at first did not appear to offer any very great difficulty has certainly proved the most difficult to install with absolute reliability of operation, and the author would like to impress this point very strongly upon any one contemplating the installation of a number of electrically operated sluice valves requiring control from a central position.

In connection with motor-driven centrifugal pumping plants where several sets are to be installed to work in parallel on the same load and pumping into the same receiving main, it is advisable to arrange for all the motors to have the same full-load slip, especially where the pumps are intended to work over a fairly wide range of output. If this is not done the pumps will not divide up the total load in proportion to their respective capacities, except when working at normal load; as for any other load, the speeds will not be altered in the same proportion. A difference of 1 per cent. in the proportionate speeds may make as much as 5 per cent. difference in the output.

Table IV. gives the capital and working costs of the plant, taken over a twelvemonth from September, 1909, to September, 1910.

Starting Torque Conditions of Squirrel-cage Motors Direct Coupled to Centrifugal Pumps.—The author is of the opinion that the driving of centrifugal pumps offers a field for the employment of motors of the squirrel-cage type even in quite large sizes, and as the present plant comprises what are among the largest high-voltage squirrel-cage motors used for driving centrifugal pumps in the country, a consideration of the starting torque properties will probably be of interest, especially as regards the actual speed attained before switching on to the normal voltage and also the time taken from the instant of closing the starting switch for the motor to attain a final velocity, which in motors of about 200 B.H.P. and upwards becomes an important consideration.

In starting up the set the pump is first filled with water and then started up with closed delivery valve, a suitable transformer tapping being employed. A centrifugal pump running at full speed under these conditions will absorb from 0·2 to 0·4 of its full rated power consumption, the proportion varying according to the type of pump. From this it will be seen that although the motor at the instant of starting is practically unloaded, it has to run up against a continuously increasing load, and if for any reason it is necessary to put a small limit to the starting current, the final speed may even be less than full-load speed. The resisting torque of the pump increases as the square of the speed, and by plotting this curve along with the slip-torque curve of the motor, we can obtain the torque at each instant available for accelerating the rotating mass, and then find the time taken to

reach a steady speed. Fig. 10 shows these curves for one of the large pumping sets, the motor being started up in a 50 per cent. tapping, giving one-quarter full-voltage torque. A calculation from these curves of the time taken to reach a final velocity showed that it was possible to form a fairly correct estimate by this means, the agreement with the actual measured time being within 10 per cent. The average time

TABLE IV.

Capital Cost and Working Expenses of Pumping Plant for the Year ending September 30, 1910.

Capital Cost.

	£	s.	d.
Transmission line and cable	853	0	0
Motors and pumps (4 sets only)	2,184	0	0
Transformers, switchgear, and connections	1,887	0	0
Sluice-valve gear and accessories	1,330	0	0
Hydraulic mains and valves	2,000	0	0
Pump well and foundations	2,200	0	0
Superstructure	3,000	0	0
Total	£13,454	0	0
Cost per B.H.P. installed (when completed)	£18	0	0

Annual Cost.

	£	s.	d.
Interest and depreciation at 7 per cent. per annum	941	15	0
Working Expenses.			
Cost of power, 157,700 units at $\frac{7}{8}$d. ...	575	0	0
Wages	600	0	0
Maintenance and repairs, including oil, waste, and stores	25	0	0
Total	£2,141	15	0

Total gallons pumped, 1,032 millions, against an average head of 19 ft.

Overall efficiency of installation ...	47 per cent.
Cost per W.H.P.-hour	5·15d.

taken to run up in the case of the 225-B.H.P. motors is 28 seconds. The motor in this case having, as already stated, a rating 33 per cent. in excess of the pump, the latter only consumes about 20 per cent. of the full load of the motor when running at normal speed with closed valve. It is, of course, preferable for the motor to attain a speed as near synchronism as possible before switching on to the full voltage, and we may take it that the slip should not in any case be more than

full-load slip so that the starting voltage employed should not be less than that required to give a percentage of full-load torque equal to the percentage of full load required by the pump when running closed at full speed, and this should not be taken as less than 25 per cent.

The motor to which the curves in Fig. 10 refer has a full-load slip of 4 per cent. with a maximum overload (torque) capacity of about 70 per cent. The dotted curve in Fig. 10 shows torque curves calculated for a motor having a full-load slip of 2 per cent., with a maximum overload capacity of 50 per cent. It will be seen from a comparison of the two curves that a small reduction in full-load slip and overload capacity means a large reduction in the net torque available for acceleration, and a corresponding increase in the running-up

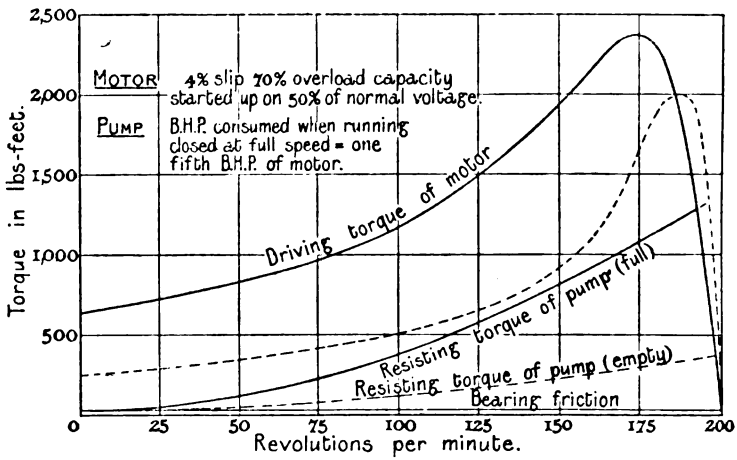


FIG. 10.—Slip-torque Curves during Starting Period of 225-B.H.P. Motor driving Centrifugal Pump.

time, which in the latter case would amount to about 100 seconds. The curves in Fig. 11 show the results of calculations of the time taken to attain a final velocity for various values of the overload capacity and full-load slip, and are based on the following assumptions: High-voltage motors of about 250-B.H.P. output on a 3-phase 50-period supply, direct coupled to pumps consuming about 25 per cent. of full load when running closed at full speed and started on 50 per cent. of the normal voltage. In making these calculations the moments of inertia of the rotating parts of the motors have been taken in accordance with the curves in Fig. 12, and the additional effect due to the pump disc and water as shown in the curves in Fig. 13.

In putting forward these curves the author does not pretend to any great degree of accuracy in the individual values shown for any particular machine, but wishes merely to indicate approximately the

general range of values covered. The values represented in Fig. 12 are fairly average of motors of about 250 B.H.P., and will increase

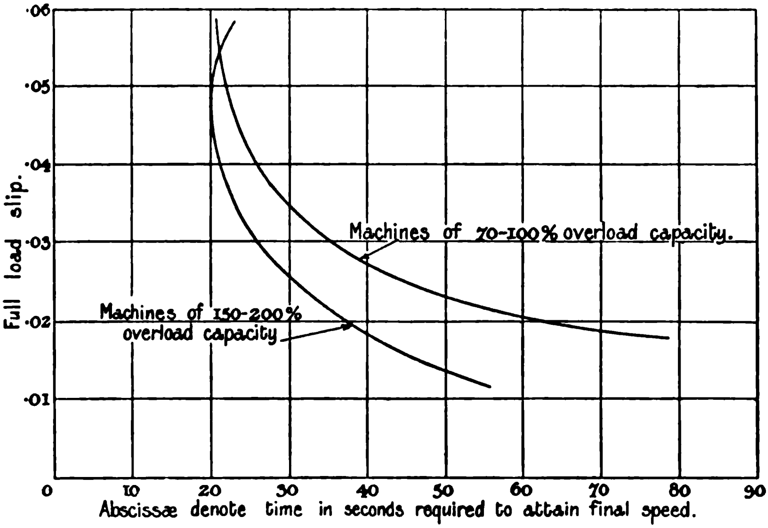


FIG. 11.—Diagram showing Average Running-up Time for Induction Motors driving Centrifugal Pumps.

somewhat with the output of the machine, the increase being less marked in slow-speed machines and machines of high overload capacity. The object is ultimately to get an idea of the time taken

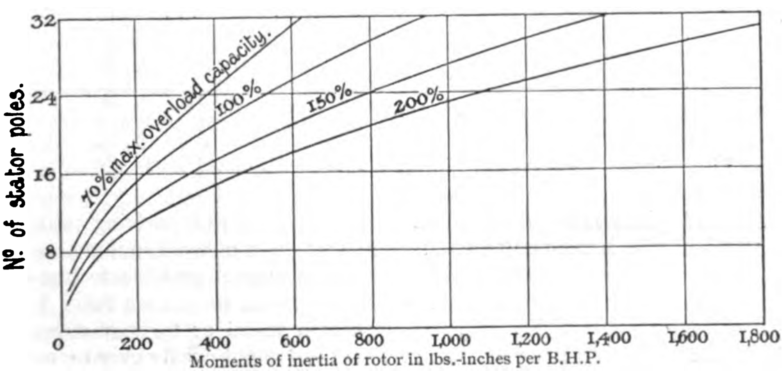


FIG. 12.—Diagram showing Approximate Values of Inertia of Rotor for Induction Motors of about 250-B.H.P. Output.

by a motor and pump to attain full speed after switching on, and while an error of 10 per cent. or so in the actual result is not of much consequence, it is important to know whether a machine is likely to take,

say, 60 seconds or 20 seconds to run up, or whether it will even run up at all. It will be noticed from Fig. 11 that it is no use designing a machine with a full-load slip of more than about 5 per cent. for large overload capacities or 6 per cent. to 7 per cent. for smaller overload capacities with the object of decreasing the running-up time.

The curves shown in Fig. 11 are applicable to both slow- and high-speed machines, and, in the author's opinion, there need be little difference between them in this respect, due to the fact that the slow-speed machines would, generally speaking, have a lower power factor. Of course, if it is attempted to obtain high power factors with slow-speed motors, there would be a considerable difference owing to the increase in weight and peripheral velocity.

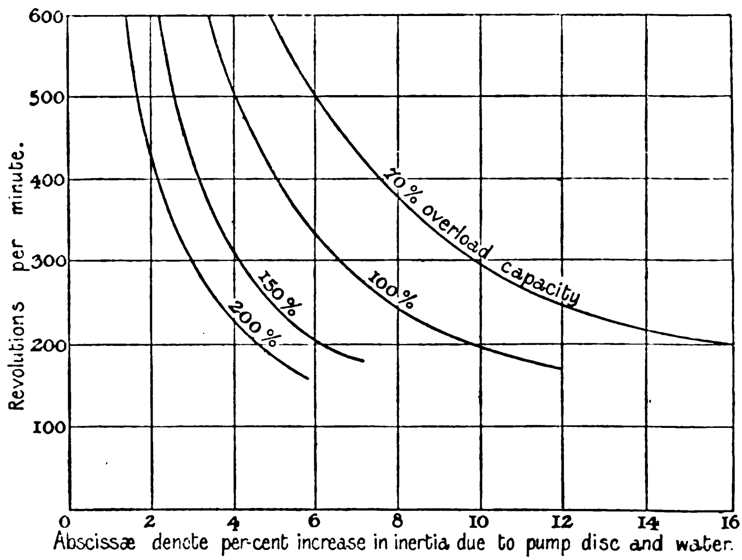


FIG. 13.—Diagram showing Effect of Inertia of Pump Disc and Water.

As regards overload capacity requirements in motors driving centrifugal pumps, it may be stated that in this class of work, pulling-over troubles are seldom experienced, as the maximum possible torque—even should the head fall to zero—is never much more than twice the normal torque, and that only in pumps with radial or forward-curved vanes; moreover, the condition of zero head could hardly ever be met with in ordinary pumping schemes short of a complete burst in the delivery mains. For this reason it is possible to permit small overload capacities where required in large slow-speed machines, such as those herein described. It also has the advantage that if the motors are, moreover, of the squirrel-cage type, the starting current can be kept within reasonable limits even when started up on half-voltage, which,

for reasons previously mentioned, is about the smallest it is advisable to employ in this class of work. These considerations appear to the author to justify the employment of large slow-speed machines of the squirrel-cage type in cases similar to the present, where the only other alternative would be gearing or belt driving.

The whole pumping plant has now been in work for nearly two years, and no trouble whatever has been experienced during that time.

The British Thomson-Houston, Company, Ltd., of Rugby, were the contractors for the whole of the electrical installation referred to in the first portion of the paper.

For the sewage pumping station, the contractors for the whole of the electrical equipment, with the exception of the 225-H.P. motors, were Messrs. Johnson & Phillips, Ltd., of Charlton, Kent. The 225-H.P. motors were supplied by Messrs. Crompton & Co., Ltd., of Chelmsford, and the whole of the pumping machinery by Messrs. W. H. Allen, Son & Co., Ltd., of Bedford.

In conclusion, the author wishes to express his thanks to those firms who have kindly supplied him with designs and information, and also to Mr. John D. Watson, M.Inst.C.E., Engineer to the Drainage Board, for permission to publish the information contained in the foregoing paper.

Discussion before the Birmingham Local Section.

Mr. W. J. Larke: The unqualified success which has attended this scheme is largely due to the enterprise and courage of Mr. Watson in recommending its adoption to the Drainage Board, because they naturally approached the adoption of electric power with considerable scepticism, and required to obtain the requisite confidence in the reliability of the scheme, as although, from the point of view of the electrical engineer, the prime movers which were replaced, consisting as they did of separate steam engines for pumping, were of an obsolete type, it must not be forgotten that they gave good and reliable service, and effectively, if not efficiently, fulfilled the conditions required, and reliability was more important than efficiency. However, it is interesting to note from page 202 of the paper that the estimated saving on the electrical transmission scheme has been fully realised, and this when taking into account the fact that not only has the extra capital cost of the electrical scheme to be paid for, but also the writing off of the value of the plant which it replaced; and in a scheme of this magnitude that the economy should be of the order of £600 per annum is a matter of gratification to electrical engineers as showing the possibilities of economy in such a case, even when on a small scale. It is interesting to note that the original scheme has been practically trebled in capacity in four years, thus demonstrating how efficient and adaptable electric power has proved in an application that is almost unique in character. On page 206 the author indicates the possibility of formulating an empirical law connecting the amount Mr. Larke.

Mr. Larke. of refuse from a given population and the amount of energy recoverable therefrom in the form of electric power, which is of considerable interest. It would be interesting to know whether the load factor referred to by the author is the ratio of the average demand throughout the year to the total demand the plant is capable of supplying, as from the figures given I am inclined to think that the load factor should not be 40 per cent. on this basis, but 20 per cent., since the second unit of the plant has not been taken into account. I would also like to ask whether the 0·875d. per unit is the actual cost based on the capital cost of the original scheme including the cost of the transmission line and sub-stations, or whether it includes only the capital cost of the generating station and the cost of steam raising. With regard to page 214, Table III., I do not think the author is justified in debiting the electric plant and the gas plant with the same amount per annum for wages. Whether the £600 there shown was correct for the gas plant or for the electrical plant the ratio between the two expenditures ought certainly to be considerably in favour of the electrical plant. On page 216 the author refers to a special type of pump. I would like to point out that this type of pump with backward-curved vanes has a very limited application, since a very material increase in power required and volume delivered results from a comparatively small increase in speed. On page 223 the author refers to the use of squirrel-cage motors, directly connected to centrifugal pumps, and I should be glad to know that these are being largely adopted wherever the generating plant is of such a character as to enable them to start satisfactorily. I would like to endorse the remarks of the author as to the suitability of these motors under such conditions for this service, particularly in connection with the rapid development of the use of turbine pumps with high speeds for mining work.

Mr. Pearson. Mr. A. PEARSON: The author is to be congratulated upon having adopted slow-speed short-circuited motors for driving the large centrifugal sewage pumps, and it is interesting to note that this type of motor has proved so satisfactory in practice. The combination of a destructor plant with a purchased supply to carry the peaks appears to be an ideal system of providing electrical power for sewage works. It is, however, strange that the steaming plant is under separate control; the curves on page 205 seem to show that the boilers do not hold their load, and the cost per unit generated is high.

Mr. Milnes. Mr. W. E. MILNES: I am sure that members who have had an opportunity of inspecting the plant at the Sewage Farm must have been impressed by the substantial lay-out of the scheme, and admired the ingenious methods of overcoming the many difficulties which had presented themselves. On page 214 the author gives an estimate of the cost of driving his pumps by gas engines and motors; he tells us that the annual costs on gas engine-driving are lower than those of electric motors. One has but to glance at the load curves on the previous page to give an emphatic denial to such a suggestion. Looking at the capital costs of the two schemes, one would think that the difference in price would

be much greater than is shown on the table. I understand, however, that the high cost of electrical plant is due to the very slow-speed motors selected, and that the figures for the gas-engine scheme are taken from actual tenders. The first item for criticism on the annual charge is the amount set on one side for interest and depreciation. Modern experience shows that although 8 per cent. is a high enough figure for interest and depreciation on a sweet-running motor, the gas engine will not only knock itself to death, but will become obsolete in a very short time, and I therefore suggest that 12½ per cent. is not too high a figure for the gas-engine scheme. The question of wages has already been raised by Mr. Larke. The estimated gas consumption I should imagine to be rather low, considering the nature of the load and the fact that the running hours of gas engines are always more than electric motors on the same work. I have not dealt with the advantages which a motor gives on the score of easy starting, reliability, overload capacity, and low cost of attendance, but conclude by expressing the opinion that electric motors should certainly be selected for work of this character on the score of cost. Stated generally, electric driving is the most profitable source of power even though in some cases it may not be the cheapest. **Mr. Milnes.**

Mr. A. HOME-MORTON: I find it difficult to decide whether this paper should be discussed in its mechanical, electrical, or sewage disposal details. Each of these aspects has its influence and bearing upon the others, so that none can be properly treated alone. In 1902, as Consulting Engineers to the Glasgow Corporation, we designed and, two years later, put to work at the Dalmuir Outfall Works what is probably the first detritus dredger of the type mentioned on page 207. The particulars are almost identical. It is therefore gratifying to find this machine, which has certainly done well, quoted as the "latest type" to-day. The lower side walls of the catchpit or channel should be sloped at from 45° to 60° to the horizontal and should be joined at the bottom to each other by an inverted tangential arch of, say, 3 ft. radius. This is more satisfactory in working than the trough bottom suggested in the paper. I quite agree that with the low annual load factor of storm-water pumping plants, as mentioned on page 211, high efficiency must give way to low first cost. It will, however, be found justifiable and good practice in installations where the pumps have to be large enough to raise, even on moderate lifts, the dry weather flow of crude sewage and to cope with the storm-water when required, to install plants which are expensive but highly efficient over the very wide ranges of duty demanded. Quite apart from the outcome of Table III., which is, at least, kind to the gas plant, I should say that, taking into consideration the very low load factor, the comparatively large power required, and the absolute need that the pumps should be "got to work with the minimum of delay," this is a clear case for the use of purchased electrical energy at any reasonable figure. Would it not have been simpler all round to have raised the storm-water against a constant head to a sufficient height and then to **Mr. Home-Morton.**

Mr. Home-Morton. distribute on to the beds by gravity? Does the author suggest, by the statements on page 218, that a gradually expanding discharge pipe improves the efficiency of centrifugal pumps only if they have radial vanes? It is difficult to follow why, after rightly deprecating the reduction of pressure by closing valve A (as shown on page 217), the author introduces, as described on page 221, the "main controlling valve"—and that of the throttle or butterfly type, which is most unusual for the duty. In the interests of charging the pumps this valve should be water-tight and air-tight, and should open automatically and gradually till discharge has full bore of the pipe free from obstruction; and, further, it should close automatically and quickly should the pump lose its water or be stopped either intentionally or otherwise. The butterfly valve has none of these attributes which are offered by the commonly used retaining valve of the clack type. Such a valve would lie at an angle of about 45°, hung from a horizontal hinge-pin at top, and be counterbalanced by a weighted lever outside the valve casing. These are, however, comparatively trivial points in an installation reflecting great credit upon both its designers and constructors.

Mr. Smith. Mr. S. P. SMITH: The remarks I wish to make are chiefly in connection with the motors. In the section "Special Type of Pump" the author mentions that the speed of the induction motor cannot be decreased without a corresponding loss of efficiency. This, however, is no longer strictly true, because means are now known whereby the speed of induction motors can be regulated over a wide range without seriously affecting the efficiency. To do this it is only necessary to take advantage of the transformer properties of the induction motor, and supply the rotor with a commutator by means of which the frequency of the rotor currents is converted to that of the supply system, so that the commutator can be connected to a pressure having the supply frequency. The excess power supplied to the stator is then no longer consumed in rotor resistances, but is paid back to the line. Either shunt or series characteristic can be given to the motor as desired. In the section "Motors" the author strongly advocates the use of induction motors with squirrel-cage rotors. Though this type has doubtless many advantages, and in many ways forms the ideal motor, there are nevertheless many disadvantages when used as in the present instance. The fact that the motor is working at the end of a high-tension transmission line may certainly give rise to surging troubles on switching in. As is well known, the more inductive the load the more likely it is that pulsations will be set up on switching in, whereas with a non-inductive load the pulsations will be strongly damped. In the present instance an auto-transformer is used for starting, which forms an inductive load. The case, of course, is just the same with a star-delta switch. Trouble may be experienced when starting up, and this is probably the reason why choke coils have been provided between the starting and running positions. Again, in order to keep the starting current small, a 50 per cent. tapping on the auto-transformer is being

used so that the starting current will be one quarter of the short-circuit current. In the present 225-H.P. motor, the short-circuit current, I am informed by Mr. Mountfort, is 3½ times the full-load current, viz., 75 amperes, so that the starting current will be approximately 19 amperes. With this current and a 4 per cent. slip the starting torque is only some 12½ per cent. of the full-load torque, which agrees with the curve marked "driving torque of motor" in Fig. 10. It will be noticed that even to obtain this very small starting torque a 4 per cent. slip has to be provided on the rotor, whereas in a liberal design 2 per cent. to 2½ per cent. might have been sufficient, thus improving the efficiency by a corresponding amount. The statement on page 224, "The motor being started up in a 50 per cent. tapping giving ½ full load," should in accordance with the above read "giving ¼ of the torque obtained with full-load pressure." As is seen, the torque is not ½ full-load torque but ⅛ at starting. Mr. Smith.

A further point on which I should like information is why the author has rated his motors so liberally. In Fig. 9 it appears that the normal rating of the pump corresponds to 20,000 gallons per minute, whilst that of the motor corresponds to 30,000, the latter corresponding to the horse-power required when the head falls to the level of the filter. Later on the author states that in no case, even with a complete burst in the delivery main, will the maximum possible torque exceed twice the normal torque. Hence it seems reasonable to expect a motor rated at the normal output of the pump to cope with any torque that may be required of it, and in the extreme case of a 100 per cent. overload it can easily be arranged for the breaker to come out, for this is clearly not a practical condition of working. On the other hand, with an ordinary fall of head, say from 20 per cent. to 30 per cent., the motor should work quite well on this overload. By rating the motors in this way much better power factors would have been obtained on normal working, whereas at present the power factors obtained lie between that of ¾ and ½ load, though the efficiency is not seriously affected, owing to the characteristic of this slow-speed type of motor. Lastly, in the case of trouble experienced by cutting the end rings of the squirrel-cage rotor, this might more or less be expected on a motor with this output, for the effect of cutting the rings in the way mentioned would doubtless be to cause the resistance of the rotor circuit to vary considerably over the pole-pitch, the effect being somewhat similar to having a single-phase rotor, though probably to a much smaller degree.

Mr. A. L. RAWLINGS: With reference to Table IV. in the paper, I should like to ask whether the 157,700 units mentioned include the current obtained from the Aston Corporation as well as that taken from the Board's own destructor station? If not, it would be interesting to know the total number of units consumed. The author gives in Fig. 7 the characteristic curves of the ordinary type of centrifugal pump. Would he kindly inform us whether he has drawn these Mr. Rawlings.

Mr. Rawlings. curves from the results of actual experiments? He shows the horse-power curves as attaining a maximum nearly in the middle of the working limits of the pump and then drooping, so that when the head is reduced to zero the horse-power falls considerably below the full-load value. My experience with centrifugal pumps of the ordinary type has always shown that a decreased head increases the demand on the motor, and I believe that this curve should continue upward with an increasing slope, so that with zero head the power taken is enormously increased. As the characteristics of centrifugal pumps are at the present time the subject of very much discussion it would be interesting to know how the author's curves were arrived at. Mr. Mountfort's experience with sluice valve motors has been an unfortunate one, but it would be a pity if anything which has been said in his paper or in the discussion on it should lead any one to think that the difficulties encountered in making these absolutely reliable are insuperable. With the experience that has now been gained there would be no difficulty in designing a fresh set of gears which would be quite satisfactory at the first attempt. Some five or six years ago I had something to do with the installing of about 120 small motors for operating railway points. The conditions are very similar, and absolute reliability is, of course, essential. These railway motors were controlled by a two-way switch in the signal-box on the same principle as the author describes. The only difference was that the railway motors were used on direct current and only three wires were necessary for each motor. The motors worked the points through a spring clutch and the limit switches were set so as to allow the motor to run for a few revolutions against the clutch after the points had been moved over. I think that if a similar device were adapted to these sluice motors it would get over a great deal of the difficulty that has been experienced. At the outset of the paper the author recommends sewage schemes to the notice of central station engineers. I hope, however, that his paper will do more than that by introducing electrical engineers and their appliances to the notice of sewage engineers, many of whom seem to display a lamentable indifference to the possibilities of electrical power in connection with drainage work.

Mr. Forster. Mr. A. LINDSAY FORSTER: I should like to draw attention to the continuous overhead earth wire, which I consider to be an element of danger, as if any such wire be necessary it is important that it should have a life equal to that of the line wires, otherwise the earth wire might fall across the line wires and cause serious damage. I congratulate the author on the courage displayed by adopting the particular form of pump vane described. This form appears to offer advantages in the case under consideration, but there is no doubt that it is not a form which would receive a very wide application, since it is limited in the range of conditions for which it is suitable and makers cannot include it amongst their standard patterns. In the matter of the running costs I wish to point out that the author's comparison between electric motors and gas engines, while probably showing

sufficient difference to cover the extra cost of the latter in stores, oil, etc., did not show sufficient difference to cover the greater cost of the gas-engine repairs, which are a very considerable item. I should also like to know why the sluice valves are operated in pairs by motors in parallel instead of by one motor geared to both valves. The switch-gear for automatic stopping and starting of motors is always liable to give trouble, and it is very desirable to keep it as simple as possible. Mr. Forster.

Mr. N. B. ROSHER: I wish to point out that the cost of 0·875d. per unit for the destructor plant is decidedly high in view of the fact that steam was provided free, the load factor was 40 per cent., and interest and depreciation were taken at 8 per cent.; a not unreasonable figure to expect under the conditions which obtained would be 0·6d. From some of the load curves in the paper it would appear that a battery would be of advantage and thereby obviate the necessity of purchasing energy from outside. In considering the various types of plant for any sewage pumping scheme in the future the claims of the Humphreys gas pump would, in my opinion, outweigh all others, both from the point of view of capital and running cost. With regard to the working expenses of the pumping plant, as the energy is apparently taken from the public supply at ⅞d., this means that the cost of purchasing and generating are the same, although steam is provided free for generating. Mr. Rosher.

Dr. GISBERT KAPP: I was connected fifteen years ago with a drainage installation, where I installed seven squirrel-cage motors having 6 per cent. slip, which were coupled to water-wheels. On receipt of a signal in the power house that water was rising in any one district the motor in that district would be started by simply dropping the voltage of the generators which fed the motors on that side of the power house and then switching in the required motor. I do not believe in guard wires beneath overhead lines, but prefer an electrically operated relay at the generating station, which would operate when the electrical centre of gravity of the system has been disturbed by a broken live wire coming into contact with the earth. With regard to the statement that the horn type of lightning arrester is unsuitable for use at 6,000 volts owing to the smallness of the gap allowing particles to lodge, a gap of 1 in. might be used on this pressure if a very thin point of wire were fixed to one horn and terminated at the correct sparking distance for 6,000 volts from the other horn. On a high-pressure surge occurring it will first of all discharge across the fine wire gap and the small arc set up would enable, so to speak, the main body of the surge to discharge across the wide gap, due to the decreased electric strength of the wide gap caused by the discharge across the narrow gap. Dr. Kapp.

DISCUSSION BEFORE THE MANCHESTER LOCAL SECTION, FEBRUARY 28, 1911.

Mr. W. CRAMP: As I know little of the details of working of a modern sewage plant, I shall confine my remarks and questions to the Mr. Cramp.

Mr. Cramp. part of the paper which more nearly concerns me. In the latter half Mr. Mountfort deals chiefly with the electrical driving of centrifugal pumps, and it is to this question that I wish to direct attention. It will be noticed that the author has drawn his curves of pressure and flow for the pumps with pressures as ordinates, so that the shape of the curve is comparable in every way with those that we are used to drawing for electrical apparatus. This is a great convenience, and it has always been a puzzle to me that many engineers draw their curves the other way about. A most interesting comparison may be made between characteristic curves of pressure and flow for a centrifugal pump and the curves of pressure and current for a dynamo, or of speed and current for an electric motor under constant pressure. It will be seen that for the pump the characteristic is of the same general shape as for the electric machine, but that the actual shape is dependent to some extent upon the shape of the vanes. If the vanes be curved backwards the tendency of the characteristic is to fall rapidly with increasing output, while if the vanes bend forward the characteristic rises at first and falls later. In the diagrams in the paper for pumps with radial vanes, the curve rises somewhat, and this is due to the fact that the fluid does not follow exactly the path of the vane, but leaves at an angle slightly in advance of the vane-angle. When the blade is sloped backwards by an amount equal to this small angle between the fluid and the vane, there should be no rise in the characteristic curve. Now similar changes in the characteristic may be brought about in continuous-current electric machines by suitable compounding, either assisting or resisting the shunt windings. By this means the characteristic may be made to rise or to fall almost as much as we please, and it therefore follows that by suitably arranging the windings of a continuous-current motor direct coupled to a centrifugal pump, and by providing the latter with appropriate blades, a combination is obtained capable of providing from constant-pressure electric supply mains any "flow-characteristic" that we desire. It may be constant head with variable quantity, or constant quantity with variable head. Either is easily obtained within certain limits, and it seems to me that the properties of the combination from this point of view are well worth careful study. In the pumping system described in the paper, polyphase motors are used, and these do not lend themselves to the same adjustments. This accounts for the fact that the author has had to shape his vanes to suit the motor, thereby sacrificing to some extent the efficiency of the combination. Had he used continuous-current motors, he might have adjusted his motor winding to suit the most efficient vane.

Referring to Fig. 9, the efficiency of the combination does not strike me as being at all high. This is no doubt partly on account of the radial vane adopted, but the disadvantages incident to this form may be considerably modified by providing the pump with a proper diffuser or whirlpool chamber, as well as with a volute. I should be glad if the author would say whether these pumps were so provided or

not. As regards the B.H.P. line in Fig. 9, I am surprised to note how nearly straight it is. For pumps with radial vanes I have been used to finding it much more curved than this. Perhaps this point might also be explained, and it would also be of interest to know how the pump efficiency in the paper was obtained, and how much of the losses in the combination were debited to the motor, how much to the pump. It is with some surprise that I notice the author's experience with end-rings that are divided up. This trouble must have been due to the fact that there was no cross-connection between the various sections, so that the rotor currents could not provide a resultant rotating field. I have used these dividing end-rings with success, but only on single-phase motors. Mr. Cramp.

Mr. S. J. Watson: I would ask whether the generating plant is run non-condensing or condensing. On page 201 the author states that the demand for power for sewage works may be anything from 5 per cent. to 10 per cent. of the output of a central station, and further on in the paper I notice that the annual consumption in this specific case is about 180,000 units per annum. I am rather surprised at that statement, because on looking up the records of the electricity department of the city of Birmingham, I find that the units sold last year amounted to about 30 millions, so that the units used by this particular sewage works only represent slightly more than the half of 1 per cent. On page 204 the author states that the load factor was 40 per cent. for 1910 and 47 per cent. for 1906, and I have been unsuccessfully trying to reconcile this statement with the other figures given—*i.e.*, an output of 180,000 units and a maximum load of 150 k.w.—which works out to a load factor of only 13 per cent. With regard to the costs, I notice that on page 206 they are given as 0·875d. on a load factor of 40 per cent. A cost of 0·875d. on the load factor of 40 per cent. is certainly high. There is not the slightest doubt that most power supply undertakings would be prepared to quote a much lower rate than 0·875d., or would certainly welcome that price if they could get it with such a good load factor. It is of interest to find that this is a case where refuse destructors have been combined with a sewage works. I had the privilege some 10 years ago of putting down a small electrical plant at our sewage works in Bury, combined with destructors. The area of the town is fairly large, and a comprehensive scheme was carried out, but in our case there is no pumping. It struck me that in the author's case it might have been worth while to consider the use of a fairly large battery to level out the peaks of the load caused by pumping. Mr. Watson.

I was interested a short time ago, when looking into the question of destructors, to hear that Birmingham was using small broken granite for filtering material, whereas it is quite the usual practice to use screened clinker for the bacteria beds. I should be glad to receive any information the author can give on this point. I think the pump efficiency of 68 per cent. given by the author is a very good figure for the ordinary commercial centrifugal pump. A friend

Mr. Watson. of mine carried out a number of efficiency tests on centrifugal pumps a few years ago, and found that the over-all efficiency was only about 40 per cent. On page 215 mention is made of the trouble experienced in Birmingham due to snow lodging between the horns of the arresters, but that they effected a cure with expanded metal hoods. I do not see how expanded metal is going to keep out snow and rain. I am surprised to find that arrangements have been made for running the private generating plant in parallel with the public supply. It is the first case of the kind I have heard of, and I consider such a course very objectionable. The usual practice is to provide change-over gear so that the private and public supplies cannot be connected.

Mr. Mallinson. Mr. A. B. MALLINSON: The adoption of electric power for sewage works is bound to come in the near future. In travelling about the country it will be observed that practically all the low-lying districts are now monopolised by sewage works. By the installation of pumping plants as described by the author, sites will, however, be obtainable without the necessity of being below the sewer levels in the streets. I have been connected with several sewage disposal equipments where the use of electricity has been important. Typical plants are at Burslem and Huddersfield. At Burslem the effluent is lifted from the levels by low-lift turbine pumps and distributed over fourteen 120-ft. revolving spreaders electrically operated. The power is taken by means of an overhead line from the town supply, there being about twenty-five motors totalling 160 H.P. At Huddersfield a large plant was started about 2½ years ago. Here the sewage settling tanks, etc., are about 1½ miles from the spreaders, the sewage flowing by gravity along an open culvert. There are sixteen revolving spreaders varying in size from 70 to 214 ft., thirteen being of the larger size. All are electrically driven by 2½-H.P. motors running on a rail round the outside of the bed. The spreaders take very little power under normal weather conditions, but the load can easily be trebled due to wind pressure in a gale. At Huddersfield there is a fairly large gas-driven electrical plant which supplies, in addition to the spreaders, the air compressors, etc. The power to the spreaders is taken by an overhead line along the line of effluent culvert. Both of these installations deal with the whole flow of the sewage from the town. I am very much interested in the whole of the paper, particularly with regard to the scheme of distributing the sewage adopted at Birmingham. I would like to ask if calculations have been gone into as to the cost per annum of dealing with the sewage as installed, which requires a head of 7 ft. behind the jet to spray it, and, alternatively, pumping the sewage up only to, say, 2 ft. above the bed to put it into rotary or rectangular distributors worked electrically. The $\frac{5}{16}$-in. holes seem small for sewage effluent. Would the author give us any information as to the amount of cleaning they require? Has any trouble been experienced due to electrolytic action between various parts of the pumps? I know of cases where it has been a prolific source of trouble with sewage water. Turning to the

motors, would the author state the amperes taken from the line at starting? Is it less than full-load amperes? The fact that on the second pump a different type of starter has been fitted would indicate that some trouble has occurred here. Would the author give his experience with the starting of these big motors? The problem of the switches for operating the small valve-motors is also interesting, and I should be glad to hear in what way the difficulties instanced by the author have been overcome. Mr. Mallinson.

Transmission Line.—As far as can be seen from the plan in the paper there seems to be no definite reason for putting the cables under the road. I presume these are private roads. Are there telephone or telegraph lines along these roads? I would like to know the type of arrester used on the 2,250-volt lines originally installed. From the paper it would appear that all the troubles experienced have occurred on the 6,000-volt line. What is the gap between the horns? Have they ever had a proper lightning discharge over the arrester? And if so, has the resistance been damaged? I consider that resistances of this nature are not at all necessary in this country. I noticed on a South Wales transmission line recently a gap of about 1¼ in. for 2,200 volts. The expanded metal guard is ingenious, and I can quite see its effectiveness. What about wind pressure, though, when there is a stiff snowstorm and it is well coated with snow?

Mr. A. G. COOPER: I notice the pump efficiency is only 68 per cent., and Mr. Watson has just said it was a good figure. I have lately been going into the question of a centrifugal pump to deliver 1,000 gallons per minute against a total lift of 36 ft., and two makers guaranteed me a 75 per cent. pump efficiency, viz., W.H.P./B.H.P. I do not know whether Mr. Watson means combined efficiency, but I expect to get 62 per cent. or 63 per cent. combined efficiency on the size of pump named. To obtain the amount of suction head I put a mercurial gauge on a pet cock on the pump and got a reading of 16½ in. of mercury. This indicated a large amount of friction for the actual lift, so I took it across the foot valve, and found that this was not responsible for the friction. I had a hole drilled in the pump side of the strainer box, which fitted right up to the pump, and obtained a reading of 12¾ in., thus showing that 3¼ in. of mercury pressure were actually lost in the pump chamber. I notice that the storm water is apparently a large amount, and I would like to ask whether they have not in Birmingham separate surface-water drains independent of the main sewers. In Colne in all the new streets such drains are laid and connected direct to the river, thus not having to deal with so much water on the filter beds. With regard to the amount of power required at the sewage works, it does not exceed 40 H.P. at the outside. Of course, in our case we have no pumping to do, but this power is only for dealing with the screens, sludge pressing, and conveying. The population of the town is 27,000.

Mr. W. B. SHAW: I notice that the diversity factor in 1906 was 1·24 per cent. and 2·40 per cent. in 1910. I would like to know how Mr. Shaw.

Mr. Shaw. this diversity factor is arrived at, as I have not yet seen any satisfactory definition of the term. According to the load factor and maximum demand the average load works out at 60 k.w. I had the impression that the diversity factor was usually taken as the ratio of the average load to the kilowatt of motors connected up, and taking the latter at, say, 300 k.w. the diversity factor obtained would work out to 20 per cent. instead of 2·4 per cent. The author mentions the drop in line as being 12 per cent., although the line was designed for 7½ per cent. I would like to ask whether in calculating the drop in the first instance allowance was made for the reactance of the line, or whether it was calculated on the resistance drop only, because it looks as though the higher figure actually obtained might be accounted for by the reactance. I should also like to know whether the generating plant mentioned works condensing, and if it does, whether the power absorbed by the auxiliaries was included in the figure taken for the total units generated in getting out the cost per unit. Also is the interest and depreciation calculated simply on the cost of the generating plant or is the transmission line and some of the equipment included in the capital outlay? With regard to squirrel-cage motors and their end-rings, I had a case some little time ago where the motor actually refused to start without load, even with 60 per cent. of the line voltage. The motor was disconnected from the pump entirely and was perfectly free in its bearings. It was not until a saw cut had been made in each end-ring of the motor that the latter would start. When that was done it started up quite normally. As regards running in parallel with mains, I should like to ask the author whether any precautions were taken with regard to the excitation of the generators in the pumping power station, because it seems to me that unless that is done it is possible to compel the mains to supply practically all the magnetising current, a state of affairs to which the Corporation engineer would probably object. With reference to motor-driven centrifugal pumping plants, the author states that where several sets are to be installed to work in parallel on the same load, and pumping into the same receiving main, it is advisable to arrange for all the motors to have the same full-load slip so as to ensure uniform distribution when the load is other than normal. If the pumps are running on partial load, does it really matter about the uniform distribution of the water, since the risk of overloading the motor does not come in? I agree with the author's recommendation that the pumps should be filled with water before starting up. It is practically impossible to get the pump away if the filling is left until after the pump has been run up. For this reason also the arrangement sometimes adopted for priming the pump by letting water back into it from the pressure main is unsatisfactory. The point is, not always; and a great deal of time can be wasted in starting up centrifugal pumps by not going about it in the right way.

Mr. Mountfort. Mr. L. F. MOUNTFORT (*in reply*): In reply to Mr. Larke, the load factor referred to is the ratio of the average annual demand to the

maximum demand on the station; I think that Mr. Larke will agree that this is the usual definition of load factor. The 0·875d. per unit includes only the capital cost of the generating station and the cost of steam raising. If the cost of transmission line and sub-stations is taken into account, the figure is approximately 1d. per unit delivered to motors. In reference to Table III., Mr. Larke does not agree that the same amount in wages should be debited to both gas and electric plants, and as several speakers have criticised the figures given for the cost of the two plants, I should like to point out here that it was not my intention to put forward the comparison as being of general application, or to imply that for work of this kind the costs of gas plant would, as a general rule, be less than those of electric plants. In the present instance the circumstances were all such as to be favourable to the gas plant, and unsuited for showing up the many points of superiority of electric plant. Under the special circumstances to which alone this comparison refers I still maintain that the figures as given are a fairly accurate representation of the cost of the two schemes. Moreover, it should surely be a matter of congratulation for those who think that electricity has been unfairly treated that the electric scheme was chosen in spite of the slightly lower cost of the gas plant. The £600 allocated to wages is a reasonable sum for the gas installation, but it only includes two men on each shift, and in an extra-high-tension electric station it would be unwise to allow one man on a shift, and therefore the wages cost cannot be smaller for the electric plant, although it is admitted, of course, that had the plant been larger such as to require more men for the gas plant, this item would have shown in favour of the electric scheme. Mr. Larke considers that the radial-vane pump has only a limited application owing to the large variation in power and output resulting from a small change of speed, and Mr. Forster also thinks that for this reason makers cannot include it among their standard patterns. While this is no doubt true to a certain extent, I do not see why it should be considered a disadvantage. The requirements of a pumping load may range all the way between constant volume, with variable head and constant head with variable volume. With constant speed the radial-vane pump is well suited to the latter requirement, and there is no doubt that for motor-driven pumps constant speed working is the best for all conditions. The reason why makers have not standardised the radial-vane pump is probably on the score of efficiency. The velocity of whirl of the water on leaving the disc is very great, and if a good efficiency is desired at the pump outlet branch, a very large diffusor is required, thus adding to the cost of the pump. If this is not done the efficiency of the pump will not generally exceed 55 per cent. The required efficiency can, however, be obtained equally well by leaving out the diffusor and providing a gradually expanding delivery pipe at the pump outlet in which the high discharge velocity head is converted into pressure head in the same manner as, and with greater efficiency of conversion than is

Mr. Mountfort.

Mr. Mountfort.

obtained in a diffusor. The reduction of velocity is in any case necessary, as the high discharge velocity required by the large velocity of whirl (in the pumps under discussion this is about 20 ft. per second) is far too great for the pipe range. The size of the pump can then be considerably reduced, and the cost of the expanding pipe is no greater than the cost of the same length of uniform pipe of greater diameter which would be required if the pump were provided with a diffusor. If the variation in volume is effected by throttling the discharge the reduction of efficiency for a given reduction in volume is far less for radial-vane pumps than for vanes with large backward curvature, although the maximum range of discharge obtainable will not be so great. As regards standardising I see no reason why a well-designed line of pumps should not include impellers having discharge-vane angles covering a large range of values, say, from 15° to 135°. This would enable a given pump casing to be used for a large number of speeds and outputs, since the external dimension of the impeller would remain the same.

Mr. Milnes, in criticising the comparative costs in Table III., considers that the amount set aside for interest and depreciation—viz., 8 per cent.—is not nearly high enough for the gas plant. In a recent paper* Messrs Andrews and Porter have fully justified this figure for gas plant, and subject to a proper allowance for maintenance and repairs I do not think the figure is too low in the present case. The gas consumption has been estimated at 25 cub. ft. per B.H.P.-hour, which is certainly a fairly liberal allowance. Mr. Milnes concludes by saying that electric driving is the most profitable source of power, even though in some cases it may not be the cheapest. I quite agree with him, and this is exactly one of those cases.

In reply to Mr. Home-Morton, I agree with him that it would be better to curve the bottom of the catch-pit than to provide a narrow trough in which there is very little clearance for the buckets. I also agree with him that where the whole of the sewage and storm-water has to be pumped, it is best to install expensive but highly efficient machinery to deal with it. It will be seen from the table of load factors, which I give on page 213, that in this case, even when the plant is required to deal with storm-water up to six times the dry weather flow, the load factor may be as good as 20 per cent., and from my experience this is just about the value beyond which it will be advisable to install high-efficiency reciprocating pumps as he himself has done in Glasgow. I do not quite follow Mr. Morton's remarks with regard to the use of the main controlling valve. I have certainly deprecated any regulation of the quantity discharged by means of valve A (Fig. 8), but a main valve of some description is certainly required there for the purpose of charging the pumps, and also for shutting off the pumps from the pipe range for repairs or inspection. There is no doubt that the clack valve suggested will fulfil this purpose to a certain extent, but it has no advantages in this respect over a valve of the butterfly

* *Proceedings of the Institution of Electrical Engineers*, vol. 43, pp. 3–40, 1909.

type, with the exception that, perhaps, it will close automatically should the pump be stopped. With such a low head as 20 ft. this requirement is hardly necessary for the purpose of protecting the pump from shock. On the other hand, the clack valve and its casing will certainly offer more resistance to the flow of water even at full discharge than a valve of the butterfly type with a properly curved door, for which the resistance when full open has been found to be negligible in the present case. Moreover, the butterfly type of valve allows of absolute control should such be required for any purpose, and it has been found tight enough to enable the pumps to be charged without any difficulty. As regards an expanding discharge pipe, its use is, of course, attended with a certain amount of gain in all types of centrifugal pumps, but the increase in efficiency with backward-curved vanes is comparatively small, and it is not usually considered in the guaranteed efficiency of the pump. All that the expanding pipe does, is to convert the velocity head of discharge into pressure head, and as this velocity with ordinary pumps does not usually exceed 8 to 11 ft. per second, the total gain in head, even assuming 100 per cent. efficiency of conversion, will not be more than 1 to 2 ft. In radial-vane pumps this discharge velocity (assuming the pump is not provided with a diffusor, in which case the expanding pipe is not required) for maximum efficiency requires to be about twice the values given above, giving four times the gain in pressure head due to the expanding pipe. Mr. Mountfort.

Mr. Morton's suggestion to pump against a constant head and then feed the filters by gravitation is certainly one that would commend itself to most engineers, but in this case would have necessitated the construction of a receiving reservoir in which the water-level would have been about 20 ft. above the existing ground-line, and I am of the opinion that the extra expense would not have been justifiable. The present arrangement has not given rise to any serious trouble of a nature such as would have been obviated by this method. I am interested in Mr. Smith's description of the method of varying the speed of an induction motor without undue loss of efficiency by supplying the rotor with a commutator by means of which the frequency of the rotor currents is made the same as that of the supply. This will, no doubt, be of considerable use in cases where a variation of speed is required, but the introduction of commutating machinery certainly gets very far away from the ideal simplicity of the squirrel-cage rotor. Quite apart from the question of the practicability or otherwise of efficient speed regulation, there is no doubt that, with a number of pumps working together on the same load, regulation of the discharge by varying the speed of individual units is not advisable and constant-speed working is to be preferred. Mr. Smith considers that squirrel-cage motors are unsuitable for working in connection with high-tension transmission lines owing to the possibility of trouble due to surges caused by switching in. Disturbances of this kind are, no doubt, more likely to arise with squirrel-cage motors and auto-transformers than with motors which

Mr. Mountfort.

are started up on non-inductive resistances, but the transformer can easily be made to withstand these momentary pressure rises, and the transmission line is generally constructed to withstand greater static disturbances than are likely to be caused by switching. The 50 per cent. tapping was not chosen with any regard to the starting current, but because it is the lowest tapping which it is advisable to employ in running-up centrifugal pumps for the reasons already mentioned on page 225 of the paper. I do not think a 4 per cent. slip is unreasonable in a squirrel-cage machine, although I must admit that this could have been reduced considerably in a machine of the slip-ring type. The slight gain in efficiency, however, would in the present case have been entirely negligible owing to the very low annual load factor. With reference to the high rating of the motors, it was at first thought that the power consumption of the pumps with low heads would increase more rapidly than was afterwards found to be the case, and, as explained in the paper, the condition to be guarded against was that of the head falling to the level of the surface of the filter beds. This condition might occur through the electrically controlled sluice valves failing to shut down when taking off a pump, or through one of the pumps losing its water, either of which conditions would result in throwing a big load on to the remaining pumps. As the pumps are frequently working through the night, when the switchboard attendant cannot see the filter beds, it was feared that this condition might last long enough to cause risk to the machine if it were to be dealt with entirely by the overload capacity of the machine. Experience has proved, however, that the motors could have with safety been rated much nearer to the pump than they have been. I think Mr. Smith's explanation of the pulsations of the rotor currents with divided end-rings is correct, and that under these circumstances the rotor behaves more or less like a single-phase machine. In reply to Mr. Rawlings, the figure of 157,000 units in Table IV. is only the power obtained from the Aston Corporation, and does not include any taken from the destructor station. With regard to the curves in Fig. 7, these are taken from actual experiment, and the power curve does actually drop beyond a certain point when the head is reduced. This pump is specially designed to have this characteristic, and I may say there is no difficulty in obtaining this effect by suitably designing the impeller. I am sorry if Mr. Rawlings got the impression that I considered that there were insuperable difficulties in the way of electrically controlled sluice valves. I certainly do not think so, and am hopeful of being able to achieve absolute reliability of working with these valves in a short time. Mr. Rawlings appears to have had no difficulty with his motors for operating railway points, but I can assure him that if he attempted to set his limit switches so as to allow the motor to run against a spring clutch after shutting a sluice valve, he would very soon have a few broken valve spindles. I agree with Mr. Forster that an aerial earth wire to be perfectly safe should at least have a life equal to that of the line wire, and in this connection ordinary barbed wire is not, perhaps, a safe material to

Mr. Mountfort.

adopt. I have already dealt with Mr. Forster's remarks about the radial-vane pump. As regards the cost of maintenance and repairs for the gas plant, the amount allowed certainly does not appear much when considered as a percentage of the capital cost of the plant. This, however, is not the best way of determining it, but it should be considered rather in terms of the output of the plant. Messrs. Andrews and Porter in their paper have given figures of 0·015d. per unit for oil waste and stores, and 0·046d. per unit for maintenance and repairs, making a total of 0·061d. per unit. The sum of £120 given in Table III. for the gas plant represents a figure of 0·2d. per unit in the annual output, or rather more than three times the amount given by Messrs. Andrews and Porter. The extremely low annual load factor is, of course, responsible for this result, and it naturally seems reasonable to suppose that if a machine is not used it will not wear out. The sluice-valve motors are worked two in parallel on one station switch, because each unit of filter is fed by two supply pipes at opposite ends of the bed, each requiring a sluice valve for its control; and as both valves have to be operated for one section of filter, it was decided to work them in this way with the object of saving in wiring. Even with this arrangement the main pole of the sluice-valve line will carry 72 wires, and this number would have been doubled if each motor were worked on a separate circuit. Mr. Rosher considers the costs of the destructor station are unduly high, and the figure of 0·875d. per unit could have been 0·6d. It must be remembered, however, that the capacity of the station is very small, and that there is 100 per cent. spare plant installed. For this reason the wages and capital charges are out of all proportion to the annual output. A peak load requiring purchased energy is not of daily occurrence, and the initial cost of a battery to deal with such peaks would, I think, be prohibitive. I was much interested in the drainage installation described by Dr. Kapp, and there can be no doubt that the squirrel-cage type of motor was ideal for that purpose. Dr. Kapp's suggestion of the small auxiliary spark-gap for the horn arresters is a valuable one, especially for moderate voltages where the horns have to be set very close.

Mr. Cramp drew some interesting comparisons between characteristic curves of centrifugal pumps and continuous-current motors, and suggested that by suitably compounding the motor it might be possible to obtain practically constant head with a considerable variation in quantity even without necessarily employing a pump with radial vanes. A little consideration, however, will, I think, show that there are difficulties in doing this satisfactorily. In investigating the speed-torque curves for the pump at any constant head we naturally find that the speed must rise for an increasing flow, this rise being, of course, greater the more backward curvature we give to the vanes. If it is required, for example, to obtain constant pressure from full quantity to half quantity, the rise in speed from half to full load will be about 20 to 25 per cent. for backward-curved vanes and 12 to 15 per cent. for vanes radial at the outlet angle. This, of course, means a differentially compounded motor, and this type is not by any

Mr. Mountfort.

means an ideal one to work with. Even if worked well below the knee of the saturation curve, it will be almost impossible to obtain the required rise for the backward-curve vane without coming dangerously near the maximum overload point, which, as is well known, is soon reached with this type of motor. Moreover, if this were done and the two curves made to run very closely together, the combination would be extremely unstable, and there would be practically no fixed working point. The slightest increase of head would cause the pump to stop delivering altogether, while an equally small decrease would probably rush the motor beyond its maximum torque-point and cause it to stop. I am strongly of the opinion that constant-speed running is the most suitable arrangement for centrifugal pumping plants such as are here described, leaving the flow characteristics to be determined by the shape of the pump vanes. I do not quite agree with Mr. Cramp's reason for the initial rise in the pressure curve, and his suggestion for avoiding it. This feature is present in varying degrees in all pump characteristics that I have had any acquaintance with, whatever the shape of vane, and is caused by the great losses in shock and turbulent motion which occur when a pump is running nearly closed; these are greater, and therefore the rise is more marked, in a pump with radial vanes owing to the greater tangential velocity of the water on leaving the disc. With regard to the efficiency of the combination shown in Fig. 9, which Mr. Cramp thinks should be higher, I would point out that the pumps are only of the ordinary centrifugal type with cast-iron impellers and casings, and I think the efficiency obtained from them is quite as good as could be expected. The pumps are not provided with a whirlpool chamber, as this would require to be very large with radial-vane pumps, and its function can be quite well fulfilled by adopting a gradually expanding discharge pipe, which effects the conversion of the velocity head of discharge into pressure head in a more efficient manner than could be achieved by a diffusor unless the latter were exceptionally large. It is true that this is offset somewhat by the large volute friction loss due to the high velocity, but the final resulting efficiency is about the same and results, moreover, in a considerably smaller and cheaper pump. Mr. Cramp thinks that the B.H.P.-line in Fig. 9 is unusually straight for the type of pump. For a vane angle of 90° this line should theoretically be quite straight, since the tangential velocity of the issuing water is the same as that of the periphery of the impeller, and therefore the energy input per pound of water is constant. In Fig. 9 this line, however, shows a slightly decreasing slope with low heads, and an investigation into the characteristic curves of this pump shows that they follow very closely the values which would theoretically be expected from a pump with an outlet angle of about 60° instead of 90°. The reason for this is that the speed is rather high for the pumps, as explained on page 219, and therefore the radial depth of the vanes is too small to ensure that the water is sufficiently guided to follow the vane angle; and instead of leaving the disc in a truly radial direction, it evidently takes a path

making an angle of about 60° with the tangent to the periphery. In obtaining these curves the motor performance was taken as shown by the official test, from which the B.H.P. was known for any value of the current. The suction head was measured by a water-level recorder in the suction well, and a long glass water-gauge tapped into the receiving main showed the water-level on the delivery side of the pump. The quantity discharged was measured by differential mercurial gauges fixed to the expanding delivery pipes on the pumps. Mr. Mountfort.

Mr. Cramp mentioned that he has experienced no trouble with divided rotor end-rings on single-phase machines, and I think that is what we would expect, as it seems probable that a rotor with end-rings divided as mentioned would act more or less like a single-phase winding, thus causing periodic fluctuations of current. In reply to Mr. Watson, I would point out that the figure of 5 to 10 per cent. is only obtained where the bulk of the sewage has to be pumped, and this, I think, is specifically stated in the paper. In the present case only about one-tenth of the whole sewage requires to be pumped, which Mr. Watson will readily observe by comparing the black area in Fig. 4 with the whole area lying below it. As a matter of fact the higher limit given—viz., 10 per cent. of the central station output—has been exceeded in some instances. The generating plant is run non-condensing. Mr. Watson, in trying to reconcile the load factors given in Table I. with the total units given in Table III., is, I am afraid, mixing up two distinct undertakings, and as I gather from the remarks of some speakers that there is evidently a want of clearness in this respect, I would point out that the figures given in Table I. refer entirely to the power transmission scheme dealt with in the first portion of the paper, while those in Tables III. and IV. refer to the sewage pumping plant which forms the subject matter of the second portion. These are two distinct undertakings, the former consisting of a generating station supplying power at 2,200 volts to a number of small sub-stations situated at various points along a transmission line about 5 miles in length, and the latter being a bulk supply at 6,000 volts from the Aston Corporation mains which is delivered to a large sewage pumping station through about ¾ mile of cable and overhead line. The former installation was completed in 1905, while the latter has only been in operation during the last two years. The two systems are interconnected at the pumping station, so that by means of transformers the bulk supply can be used as a standby for the private generating plant. The figure of 0·875d. per unit given for the generating plant certainly appears rather high, but it must be remembered that the capacity is very small, and therefore the cost of wages and spare plant has a great effect upon the price per unit. As regards the use of batteries to level out the peaks caused by pumping, these peak loads being chiefly due to storms are not of daily occurrence and short duration as is generally the case in central

Mr. Mountfort.

station peaks, and therefore cannot be economically dealt with by batteries. A demand such as would be represented by the top of the peak shown in Fig. 3 has been known to continue for as long as 48 hours, and would require a battery of enormous capacity if any material saving in plant were to be effected. As regards the use of screened clinker for filtering material, we prefer to use broken granite or hard slag as being far more durable and lasting for permanent beds. Our experience is that clinker and such like material will ultimately tend to break down and choke the filter. If a bacteria bed is constructed of coarse-grained material so that any suspended solid matter in the applied liquid will pass through the filter, and is moreover constructed of a hard and durable medium like granite or slag, there is no apparent reason why the material should ever require to be removed and replaced. With a bed constructed of clinker or furnace ashes it is probable that the material will require to be removed and washed about every five to ten years. In the case of filters constructed to deal with large volumes of storm sewage where the load factor of the plant is bad, this necessity may be more than counterbalanced by the saving in capital cost of the bed, and the filters referred to in the paper are constructed of screened and washed gasworks ashes, which can be obtained and placed in the filter for about one-fourth the cost of broken granite. Mr. Watson expresses surprise that a private plant has been allowed to run in parallel with a public supply. If the capacities of the two stations were at all comparable this might perhaps be objectionable, but as the private plant in this case is so small, it cannot, I think, injuriously affect the public supply, and in the case of anything going wrong, the private plant would probably be the sufferer.

I was much interested in Mr. Mallinson's description of the electrically driven revolving distributors at Burslem and Huddersfield The question of adopting either the revolving or rectangular types of distributor was fully considered in connection with the scheme, but the method of spray jet distribution was far and away the cheapest, notwithstanding the extra lift required. The large number of separate distributors required to cover an area of 30 acres, together with the cost of supporting the running rails, and in the case of the circular distributors the considerable amount of wasted area, are factors which make this method of sewage distribution inadvisable where large areas of filters are required. Holes $\frac{5}{16}$ in. in diameter are not by any means small for fixed spray jets, and a large number are at work on the filters at Birmingham with an equivalent orifice of only $\frac{3}{16}$ in. The labour expended in cleaning the jets, including general attendance, requires about one man to every 8 acres, and costs about 1s. 6d. per million gallons. As regards electrolytic action in pumps, there has been one instance of this where a small pump was put down to raise water from one of the main outfall sewers, the sewage in which was of a slightly acid nature. The cast-iron impeller was practically eaten away in about five months. A gunmetal impeller was substituted, and, up to

the time of removing the pump, appears to have suffered no damage. With the large motors the current taken from the line at starting is about three-fourths of full-load current on a 50 per cent. voltage tapping. As regards the limit switches on the small valve motors, I am now experimenting with solenoid trip-gear, and believe that this will prove entirely successful. Where the transmission line has been carried in cable under roads these are public roads, and in most instances there are telegraph or telephone lines along them. The multi-gap type of arrester has been used in the generating station and sub-stations on the 2,250-volt line, but no arresters are installed out of doors. The gap between the horns on the 6,000-volt line is $\frac{3}{8}$ in. Considerable trouble was experienced before putting in the resistances, owing to simultaneous discharges across two horns shutting down the line, the system being delta-connected. I do not know if there has ever been a direct lightning discharge over the arresters since the resistances were put in, but there has been no shut-down of the line. A gap of $1\frac{1}{4}$ in. for 2,200 volts seems exceptionally large; does Mr. Mallinson know whether there was a small auxiliary gap on the arrester? Mr. Mountfort.

Mr. Cooper gives a figure of 75 per cent. pump efficiency which the makers have guaranteed him, and there is no doubt that with high-grade turbine pumps working at the particular load for which they were designed, such efficiencies can be obtained—in fact, I believe as much as 80 per cent. has been reached in some cases. If Mr. Cooper is dealing with clean water he may perhaps retain this figure, but with sewage pumps the efficiency generally falls off after a few months' working. The apparent friction loss in the pump chamber, represented by the $3\frac{1}{2}$ in. mercury pressure referred to by Mr. Cooper, may possibly be accounted for by omitting to take into consideration a difference of level in the positions of the gauges. If the position of the gauge on the pet-cock on the pump was about 3 ft. above the point on the pump side of the strainer box where the gauge was afterwards placed, the difference is, of course, at once accounted for. As regards the apparent large amount of friction indicated it is well to remember that a vacuum gauge on the suction pipe to a pump will register not only the static lift, or height between water-level in the suction bay and the surface of the mercury, together with the friction head, but also the velocity head of the water flowing up the pipe; and in ordinary centrifugal pumps this latter may vary from 1 to 2 ft. This velocity head should rightly be debited against the pump, and not included in its useful work, as it is generally entirely lost in discharge. While this may not be of much importance in high lifts, it becomes serious in low lifts, where it may amount to 5 per cent. of the total head with a corresponding effect on the efficiency. Unless this is borne in mind the user of the pump may find that its performance from water-level to water-level in actual use may differ considerably from that shown on test. With regard to the amount of storm-water, the sewers in Birmingham are partly on the separate and partly on the combined

Mr. Mountfort. system; all new sewers are now constructed on the separate system, which is being gradually substituted throughout. I think, however, that Mr. Cooper will find that, even with separate storm-water drains, a rate of flow equal to six times the dry weather flow is not unusual in the foul-water sewers in times of storm—in fact, it would be unwise to construct them of any less carrying capacity. With reference to Mr. Shaw's question regarding diversity factor, I think this is generally defined as the ratio of the sum of the sub-station maximum demands to the maximum demand at the generating station. In the present case, as each sub-station contains only one motor, the sum of the sub-station maxima is practically the same as the total power connected to the line, and as the motors are all fed through separate banks of transformers, the kilowatts input to the transformers has been assumed equal to the B.H.P. output of the motors. The diversity factors in Table I. then become $124/100 = 1{\cdot}24$ for 1906, and $360/150 = 2{\cdot}40$ for 1910.

In calculating the original drop of $7\frac{1}{2}$ per cent., allowance was made for the reactance of the line, and the increase is accounted for by increase of load. In obtaining the cost per unit interest and depreciation has been calculated only on generating and steam-raising plant, no line equipment or sub-station work being included. I am somewhat surprised to hear of the squirrel-cage motor which refused to start up on a 60 per cent. tapping, even when running free in its own bearings. Apparently the resistance of the rotor winding was too small for even the very slight torque required, although this seems hardly conceivable. No special precautions are taken with regard to the regulation of the excitation when running in parallel with the public supply. Owing to the great disparity in the relative capacities of the stations, I do not think it would materially affect the central station even if it were supplying rather more than its share of wattless current. Mr. Shaw questions whether it is necessary, as stated in the paper, for all motors to have the same full-load slip when working pumps in parallel, as it will not matter on partial loads whether the division between the various units is correct or not. This precaution applies more particularly to radial-vane pumps than to the usual form, and with this type I certainly think it is advisable. If the plant is working slightly ahead of its normal capacity the motor with the small slip will be more overloaded than the others. Again, in working at partial load the small-slip machine will be working near the summit of its characteristic, and under these conditions is liable to cease pumping, and thus throw all the load on the remaining pumps.

ELECTRIC HEATING AS APPLIED TO COOKING APPARATUS.

By HAROLD GRAY, Associate Member.

(*Paper received December* 12, 1910. *Read before the* MANCHESTER LOCAL SECTION, *January* 17, 1911.)

The slow progress in the adoption of electric cooking apparatus for domestic work in this country, in spite of its manifest advantages from several points of view, must be a source of some concern both to central supply authorities and to manufacturers. The former have a reliable and in many cases a cheap supply of electrical power at its consumer's door; the latter have a variety of cooking apparatus, much of a highly efficient description, which they are willing to dispose of.

There must be some underlying factors in the problem which militate against the more general adoption of electrical energy for use with cooking apparatus, and the author has endeavoured in this paper to bring forward the strong and weak points of the electrical system, in order to enable a discussion to take place which may tend towards advancing the use of electrical energy in this direction.

The essentials which bear on the success or failure of electrical cooking are :—

Reliability of the apparatus.
Efficiency of the apparatus.
Utility, *i.e.*, good practical design to attain the object in view.
Cost of apparatus.
Cost of electrical energy.

Reliability of the Apparatus.—The operators in the domestic field are generally unskilled in the engineering sense, often careless, and with small elasticity of mind. This being the case, it becomes essential that all apparatus passing through their hands must be (as far as external manipulation at least is concerned) of the simplest possible character combined with great robustness. These remarks do not, of course, apply to the intelligent housekeeper under whose charge the very few complete electrical cooking installations now working are generally controlled; but if any real development is to be expected, it means that the apparatus will be in the hands of the usual domestic servant,

whose business in life is to cook and not to look after electrical machinery. We all know the very substantial character which electrical apparatus has to assume in a workshop where the operatives have at least a certain sense of the strength of materials and where there are always a number of highly skilled engineer foremen. How much more is it necessary to ensure "fool-proofness" in apparatus in a private house where the operators are quite untrained in the engineering sense.

Immunity from breakdown is a most important consideration. A breakdown or failure to do its work in any piece of electrical cooking apparatus under ordinary treatment should be rendered practically impossible. An electrical breakdown very generally means connection to earth, *i.e.*, the shell of the apparatus becomes charged unless the shell is connected to an earth wire. A shock is probably the result to the operator, which may assume dangerous proportions if the hands are impregnated with soda or salt. An experience of this sort may so alarm the operator that she will decline to have anything further to do with electrical cooking. For this reason, if for no other, a regulation should be rigidly enforced that all apparatus should either be connected to an earth wire, or as a less satisfactory arrangement, rest on an earthed metal table.

Efficiency of the Apparatus.—In considering efficiency it is advisable to look into other forms of domestic heat application. The two principal sources of heat now used in cooking work are obtained from coal and gas. We may probably eliminate the coal source from consideration, owing to the fact that gas has competed with and ousted coal from the field in the great majority of small cases. Coal is only holding its own where good cooking is considered as a necessity and in very big establishments.

Thus electrical cooking has to compete against gas cooking, and unless it can be shown in practical working to do this on an average basis, its success amongst the mass of the people can never hope to be attained. A comparison of the crude heat obtainable from gas and electricity for the same money payment will here be of interest.

Assume gas to be 2s. 6d. per 1,000 cub. ft., and that it gives out 600 B.Th.U. per cubic foot,* and that electricity is ¾d. per unit and gives out 3,400 B.Th.U. per kilowatt-hour.

Thus gas gives 600,000 B.Th.U. for 2s. 6d. or 20,000 for 1d., and electricity 3,400 B.Th.U. for ¾d. or 4,532 for 1d.

At these assumed prices it will be seen that four times more crude heat is available for a given price with gas than with electricity. Under these circumstances the vital necessity for the highest possible efficiency which is reasonably obtainable in electrical cooking apparatus will at once be recognised in order to overcome the crude heat advantage which gas has over electricity at the prices instanced.

It will probably be admitted that ¾d. per unit is a reasonably low

* Owing to the quantity of water gas which is now mixed with town gas 600 B.Th.U. per cubic foot will probably be a fair average.

price for domestic power, and ½d. the very lowest price which will be obtainable from any supply authority for a considerable time to come, and will, without doubt, be much lower than the average taken throughout this country for, say, the next ten years.

In considering the question of efficiency it is necessary to split up cooking work into two broad classes, viz. :—

A. Boiling, frying, etc., in which the basis is the transmission of heat to a liquid, such as water or fat, which may in turn heat some other food.

B. Roasting, baking, etc., which is carried out in ovens and in which the basis is the application of heat energy to air, which air passes heat on to the food to be cooked.

In arriving at efficiencies in Class A the author has taken the basis as the evaporation of 1 lb. of water from and at 212° F. In efficiency

TABLE I.

Water Evaporated.	Gas in Feet per Hour.	Duration of Test.	Gas in Feet Used.	Pence / Lb. Water at 2s. 6d. per 1,000.
Lbs.		Minutes.		
1	3	99	4·95	0·1480
1	4	66	4·45	0·1330
1	6	42	4·20	0·1260
1	8	31	4·13	0·1239
1	10	24	4·15	0·1245

tests the actual raising in temperature of the vessels and liquid to 212° F. has been eliminated.

It is advisable to have before us the practical efficiency of the gas-ring system for comparative purposes and a number of gas tests have been taken, the average results of which are shown in Tables I. and II.

All evaporation tests, electric and gas, were taken under the following conditions: The entire heating unit with containing vessel and water were balanced on one side of a pair of accurate scales against weights on the other side. The weight which had to be evaporated was then removed from the weight side, and the test was completed when the balance was again established on the scales due to evaporation of water equivalent to the weight removed.

There was no appreciable error due to frictional effect of the connections, viz., flexible wire or rubber gas pipe, as the connections

were in all cases more than 4 ft. long in a horizontal span, and of course were included in the total weight at start and finish of tests.

The maximum gas applied in the gas tests was sufficient to allow of the flames just being visible all over the bottom of the cooking vessel in the dark. The standard gas-ring employed was of the most modern design obtainable. The gas-meter used was a standard one made by W. Sugg & Co.

A curve drawn from this table shows that the efficiency increased with the quantity of gas used up to 9 ft. per hour, when it started to decrease. This point where the curve turns is practically the point where the flame overlaps the bottom of the pot. The efficiency is lowest at the lowest recorded gas consumption, and steadily increases as more gas is used up to a certain point; this is probably accounted for by the fact that the radiation losses of the cooking vessel are a constant quantity over a given period, and hence the quicker the time in which the evaporation is carried out the higher is the overall efficiency. The column $\frac{\text{pence}}{\text{lb. water}}$ is the most important from a practical point of view. The average cost of gas in this column per pound of water evaporated from and at 212° F. is 0·131d.

TABLE II.

Quantity of Water.	Gas in Feet per Hour.	Duration of Test.	Gas in Feet Used.	$\frac{\text{Pence}}{\text{Lb. Water}}$
Lbs.		Minutes.		
1	3	17	0·855	0·0256
1	4	12½	0·830	0·0249
1	8	6	0·800	0·0240

Table II. shows the gas heat required to raise the cooking vessel and water from cold (62° F.) to 212° F. with various consumptions of gas. The vessel in this case was a 2-pint thin enamelled steel one (the same as the one used in Table I. tests) weighing 13 oz.

Taking the average result of the last column in Table I. and Table II., and adding them together, we have as a result the gas cost to raise 1 lb. of water from cold to boiling, and to evaporate this off—viz., 0·156 $\frac{\text{pence}}{\text{lb. water}}$.

We now come to the efficiency of electrical cooking apparatus under Class A. The apparatus has not yet settled down to any standard design, in some cases hot plates being used with ordinary flat-bottomed vessels and in other cases self-contained electrical vessels, while occasionally a combination of hot plates and self-

contained vessels is employed. Table III. gives the average of tests of the cost in pence per pound of water evaporated from and at 212° F. under similar conditions to Table I. No account is taken in this table of the heat required to raise water or apparatus up to 212° F. In all cases it was found that the fastest heating speed obtainable was the most efficient one.

TABLE III.

Class of Vessel.	Water Evaporated.	$\frac{\text{Units}}{\text{Lb. Water.}}$	Cost (¾d. per unit) $\frac{\text{Units}}{\text{Lb. Water.}}$	Efficiency assuming Theoretical as $0{\cdot}284\,\frac{\text{Units}}{\text{Lbs}}$.
	Lbs.			
Self-contained 1-pint saucepan	1	0·312	0·234	91·0
Self-contained 3-quart water-boiler	1	0·348	0·261	81·6
Frying-pan (aluminium) ...	1	0·379	0·284	75·0
Flat-bottomed aluminium 2-quart saucepan on hot plate	1	0·435	0·326	65·2
Flat-bottomed earthenware pot on hot plate	1	0·455	0·341	62·4

Table IV. gives the cost of raising 1 lb. of water with identical apparatus from 61° F. to 212° F., which is of use when considering

TABLE IV.

Class of Vessel.	Water Heated.	$\frac{\text{Units}}{\text{Lb. Water}}$	$\frac{\text{Cost}}{\text{Lb. Water}}$
	Lbs.		
Self-contained 1-pint saucepan	1	0·055	0·041
Self-contained 3-quart water boiler	1	0·061	0·045
Frying-pan (aluminium) ...	1	0·080	0·060
Aluminium saucepan on hot plate	1	0·124	0·093
Flat earthenware pot on hot plate	1	0·133	0·100

quick heating up in contradistinction to long-hour work. The hot-plate tests started from cold.

Taking the best figures in the last columns of Tables III. and IV. and adding them together—*i.e.*, the cost in pence to raise 1 lb. of water from cold to boiling and evaporate it—the result is 0·275d. per pound. The result of the vessel giving the highest efficiency is taken, as this is the one which is the nearest to the gas-test conditions—*i.e.*, it is dealing with its full capacity of water.

From the last column of Table III. it is seen that the efficiency—*i.e.*, ratio of heat converted to useful work to heat applied—is with the self-contained vessels very satisfactory; in fact, very little more can now be practically done in the direction of improving this. The hot-plate efficiency is, as is to be expected, considerably less, but other considerations are involved in the use of the hot-plate system, which are dealt with later.

B. Oven Efficiency.—The obtaining of the efficiency of ovens is a much more difficult matter than that of the cooking apparatus in

TABLE V.

	Size of Oven in Cubic Inches.	Weight of Bread.	Time.	Power Used.	$\frac{\text{Cost}}{\text{Lb. Bread}}$
		Lbs.	Minutes.		
Gas ...	6,400	8	58	31 ft.	0·116d. at 2s. 6d.
Electricity	6,137	9	52	0·92 units	0·076d. at ¾d.

Class A. The water-evaporation test gives somewhat unsatisfactory results and is of not much practical value, as the temperature in the cooking chamber in ordinary work ranges up to 400° F., *i.e.*, almost twice the temperature at which the water-evaporation tests would be taken. The author has been forced to resort to the test of the actual quantity of energy required to cook a given weight of food, and has taken white bread as the standard to work upon.

The figure for the cost of electricity per pound of bread is the average of seven tests taken over a lengthened period. The figure for gas is the average of four tests.

The tests were started at an average of 380° F. and finished at an average of 350° F. The heating up from cold is not included, as for such a short cooking period the energy required to heat up is an abnormal percentage of the total and gives an incorrect idea regarding the true practical energy consumption on oven work.

It will be seen that the electrically cooked bread takes a shorter period to cook than that done in the gas stove. This is due to the more uniform heat in the electric oven, and hence the door not having

to be opened so often. The cooking in the gas oven in these tests was not of a satisfactory nature.

In looking at these tables generally, it will be seen that with the small cooking vessels gas is cheaper than electricity at the prices named, but with ovens there is a great advantage lying with electricity. The total amount of energy taken by the small pots and pans in working practice is only a small proportion of the energy taken in oven work, varying from 25 to 35 per cent., so that in general practice there is little reason to doubt that for overall economy electricity can and does compete with gas in price if suitable apparatus is forthcoming.

Utility of Appliances.—The consideration of this branch of the subject is at the present time of considerable importance. The variety of appliances and the number of different systems are calculated to confuse entirely the mind of the would-be user, and unless he is very fortunate he will probably buy some apparatus which, instead of showing the convenience and satisfactory results accruing from electrical cooking, will thoroughly disgust him and make him revert to his previous method of operation.

Up to the present time there is no system on the market—so far as the author is aware—in which connecting wires to the electrical appliances are not used, and it is likely to take some little time before a wireless system of connection to the supply is elaborated. All systems and appliances therefore start off with this common handicap.

As to appliances themselves, the chief rivalry is going on between what are called the "hot-plate" system and the "self-contained" system, both of which have advantages in different directions.

In the hot-plate system one or more single or variable speed hot plates are used in connection with ordinary cooking vessels, care being taken that the bottoms of the vessels are as flat as it is possible to get them. The hot plates, not having to be moved, can be connected to the supply by metal-sheathed wire and efficiently earthed, and there is no risk of shock to the operator. The cost of the hot-plate system is less than the self-contained one, and the simplicity of operation is much improved. The principal objection is the low efficiency, as seen from Tables III. and IV. The question as to whether this low efficiency is a serious disadvantage or not depends entirely on the price per unit paid by the consumer. A price above ½d. per unit is likely to render this system prohibitive if used for all purposes, due to high cost of power, except where price considerations are of no moment.

In the self-contained system each vessel has its own electrical heating gear, generally with three or four different heats controlled on the series parallel system by means of three plugs and contact pins. No attempt is yet made by the generality of makers to earth the appliances. When this is done an additional flexible wire is required to be run from the vessel to the main earthing-point, making three wires per vessel as a minimum. The use of flexibles and plugs is a somewhat objectionable feature of this system. It has, however, the advantage of portability—*i.e.*, the vessel can be moved easily and heated up

anywhere in the house where there is a supply—and it is much less cumbersome in this respect than the hot-plate system.

The great advantage of the self-contained system is in respect to its high efficiency; the higher the price of power is, the more necessary it is to adopt this system. The reliability of the electrical part of the vessels has much improved during the past eighteen months, and there is now little risk of burning these out, except through excessive carelessness.

The materials employed and the difficulty of efficient cleaning in vessels made by some makers is not above criticism. Owing to a complaint by a consumer, the author recently examined a series of vessels marketed by a manufacturer in which the electrical parts were excellent. The vessels, however, were constructed with a brass bottom and copper sides, the brass being soldered to the copper. The vessels were lightly silver plated, which plating all worked off after one or two scourings. A sharp right-angle bend between the sides and the bottom added to the difficulty of cleaning. Metallic poisoning is the inevitable result of such construction.

Solid-pressed aluminium appears to be a good all-round metal if kept thoroughly clean, its only disadvantages being that it does not attain such a bright lustre as copper or brass. Cast aluminium is objectionable as it is liable to be porous, and hence dirt lodges in the pores.

The most important piece of cooking apparatus in general use and the one which is most difficult to make satisfactory in operation is the cooking oven. The great bulk of the work is done in this and it has to be capable of turning out good material. Some makers follow the lines of the gas ranges and endeavour to combine the oven with hot plates or similar arrangements. Others make the oven an entirely separate piece of apparatus, and this arrangement appears to give the most satisfaction in practice, except where space is extremely limited. The essentials of a satisfactory oven are :—

1. Rapidity of heating up to cooking temperature.
2. Good arrangements for heat conservation.
3. Reliable and simple electrical gear.
4. Cooking operations to be better and more easily carried out than in either coal or gas ovens.

The average temperature of oven cooking is about 350° F., varying from 250 to 400 for various applications. To be of real service this temperature of 350° should be attained from cold, say 60° F., in about 15 minutes. This high speed of heating up is not only a convenience but also an economy, as the "idle period" radiation losses are reduced thereby. A 15 minutes' heating speed involves a somewhat heavy demand on the supply mains; thus an oven of a cubical contents of 3·55 ft. requires 3 k.w.—*i.e.*, $0{\cdot}84 \ \frac{\text{k.w.}}{\text{cub. ft.}}$ as a minimum, and this will be exceeded if it is not efficiently constructed.

The heat energy applied inside an oven is utilised in three ways:—

(a) In converting the crude food into the finished article.
(b) Loss due to radiation.
(c) Loss due to hot air escaping principally experienced when the door is opened.

(c) may and generally does form by far the biggest percentage loss, and if the oven can be arranged so that the door is practically never opened except when the food is taken in or out great economy in heat energy is effected.

The author has spent some little time in working out this problem, and there appears to be very little doubt that the whole secret of success depends on two things: viz., uniform heat throughout the cooking area, and a steady movement of the hot-air currents in the correct directions, to avoid "airlocks" over and around the food. If these two factors are in operation the cooking is perfectly uniform

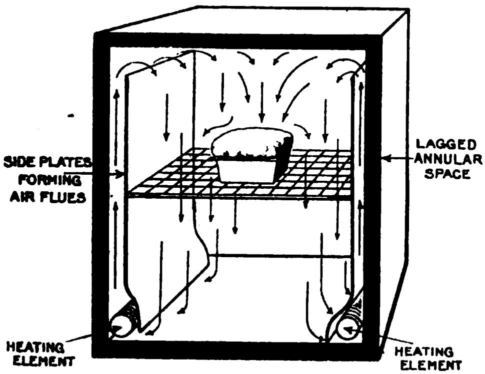


FIG. 1.

throughout the oven, the food does not require to be moved periodically, and hence the oven door does not need to be opened unduly. If the door is not to be opened for inspection it is, of course, essential that there be a light inside and an inspection window. A thermometer is also a practical necessity, as with a well lagged oven it is impossible to estimate the temperature inside from feeling any external part.

To attain a practically uniform heat round all parts of the food, particularly in big sizes of ovens, presents some difficulties. The arrangement eventually adopted by the writer was to generate the heat at the bottom, deliver it then into vertical "flues," the flues passing it into the oven proper at the top. The hot air is then forced from the tops by fresh hot air continually rising in the flues—through all the area containing food—to the bottom, where it again comes in contact with the heating elements and the process then repeats itself. Fig. 1

shows the direction of the air currents in a diagrammatic manner. The circulation of air from top to bottom is absolutely certain as long as heat is being generated, and there is a slight wastage of heat always going on due to absorption of heat by the food and heat leakage which tends to make a slight reduction in the temperature of the air as it is moved from the top to the bottom. This difference in temperature in practice is found not to exceed 15° F. when cooking temperature is attained, and with this difference the speed of the air is quite sufficient to sweep away all "air-locks" from the top and around the food. This slight temperature variation which is not 5 per cent. of the total temperature is not sufficient to affect practical uniformity of cooking from top to bottom of the oven.

With regard to retaining the heat in the general body of the oven, the general practice is now to have the oven double-jacketed, with the hollow walls filled with dry air retained in a cellular state by means of finely divided asbestos or slag wool. Both of these materials give excellent results if the jacket is made 1½ in. to 2 in. thick.

The electrical gear has in the past been one of the weakest details in oven work. The style of heating element employed, provided it is of sound construction and long life, is not of much importance; no particular alloy of metals can have a better efficiency than any other alloy, as we know that the element is only a means of converting a definite quantity of electrical energy into a fixed amount of heat energy, and the question of the use of radiant heat or low-grade heat is of little importance in practice provided the right temperature is attained in both cases. The connections of the elements to the switchgear and the design of the switchgear itself is, however, of considerable importance. The elements should, to avoid a risk of breakdown, be connected directly to the switchgear connections, but at the present time this is seldom done, a number of small nuts and bolts being very often employed to make the connections which, in the high temperature and with "sweating" occurring on cooling down, are very liable eventually to give trouble.

The switchgear itself should be simple and unbreakable. The use of tumbler switches, although the cheapest arrangement, is to be deprecated, as with the heavy currents required they may burn out very quickly in unskilled hands. A small controller operated by one handle appears to give the best results, and only two heating speeds —"fast" and "slow," and "off"—are really necessary.

There is no doubt that well-designed electrical ovens give vastly improved results over gas and coal ovens. Uniform heat, which means an increased cooking speed, a pure internal atmosphere, and simplicity of control, ensure the user never reverting to the old style provided the cost per unit is reasonable.

It is only by practical trial and error that the most effective "cooking unit" can be arranged. The author has found a combination of hot plate and self-contained apparatus, together with an independent oven, to give the most satisfactory results. Such a set for use in a

small house is shown on the lecture table. The self-contained vessels would be used for all short-time work and most of the other work. The hot plate is useful for long-hour work for cooking with ordinary pots or fireproof china vessels. In combination with the above is arranged a "distributor" for the purpose of conveying power in a neat way to the apparatus.

The most marked feature of many cooking installations is the untidy flexible wire lying about on the cooking table; and this distributor has been designed to avoid this, and also to collect all the electrical cooking apparatus together and effectually to control any one of them if a breakdown occurs. It will be seen that this particular distributor has six "ways," one for each electrical vessel and one heavy way for the oven. When any vessel is out of use its flexible

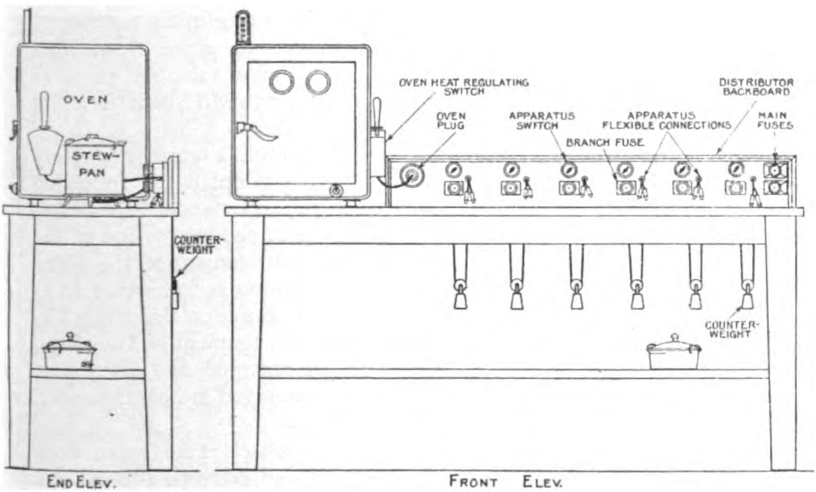


FIG. 2.

wires run away—being operated on the telephone jack principle—and leave the cooking table clear. When in use the wires run direct to their respective vessels without any "snaking." A fuse and switch control each way and a D.P. fuse controls the whole distributor. This distributor is screwed on to the cooking table or fastened on to an adjacent wall, and is supplied with power from a wall plug in the usual way. Fig. 2 shows the general arrangement of this.

It is to be regretted that up to the present manufacturers have not evolved real "turn-down" cooking apparatus; by this the writer means apparatus in which the heat can be regulated as easily and as finely as with a gas tap. The nearest approach is the usual standard 3 or 4 heat series-parallel adjustment, which has to be worked generally by removing and replacing plugs, and is a troublesome device under the best conditions.

One firm of manufacturers supply apparatus in which only one plug is employed, which is pulled out, rotated, and replaced to effect the 3-speed regulation. This arrangement is a distinct improvement, but it is still awkward, and requires both hands to operate.

A requirement in vessels used for boiling is what is known as "simmering." It is only by chance that a series parallel control supplies exactly the right amount of heat for this operation, and an attendant has consequently to stand over the work and ring the changes on the plugs, with consequent loss of time and an unsatisfactory result.

The writer has recently been testing a new hot plate by a firm in which the soundness of construction probably surpasses any other he has examined. Unfortunately it is fitted with a 1-speed heat only, which renders it practically useless for general cooking work. Where economy in power is a consideration it is also bad for quick heating.

A hot plate with a graded regulator to turn its power down from full to $\frac{1}{10}$ full (say 80 watts) would be a very valuable piece of cooking apparatus. So small a power as 50 watts will maintain a pint of soup at 120° F.

To overcome this "turn down" difficulty until a more satisfactory arrangement can be devised, the author has adopted the following arrangement: A hot-water boiler with a 3-speed standard heater is fixed in a permanent position and connected in series with one of the "ways" on the distributor. Thus the electrical element of the water boiler is in series with any cooking vessel which is connected on to this "way." If a 3-speed series parallel vessel is put on this "way" in series with the water boiler by varying the arrangement of the plugs, no fewer than twelve heating speeds can be obtained, and every watt of power not used on the cooking vessels is employed in heating water, so much of which is required in domestic work.

It is seldom that independent cooking vessels take more than 600 watts maximum, and a suitable size for the water boiler is 800 watts on the full voltage.

Cost of Appliances.—The high cost of good electrical cooking appliances is a source of complaint in many quarters. We must recognise, however, in considering this, that the output is yet extremely limited and general design not firmly established; hence manufacture on factory lines with large outputs is not being undertaken. Reliability has been attained and design is rapidly improving. Large outputs only are now required to reduce prices very considerably. Probably a co-operative scheme amongst supply authorities, in which a large quantity of one standard article was to be ordered at one time, would be the best means of rapidly reducing prices to a popular level.

Cost of Electrical Energy.—The price per unit at which power can be obtained for domestic uses will ultimately be the most important factor. Two public authorities already supply at ½d. per unit. A considerable number charge 1d., and the range of prices in the future is likely to generally be between these two figures.

A charge of over a 1d. per unit will generally confine the use of electrical cooking gear to well-to-do people with whom the somewhat increased cost over gas or coal is negligible compared with the advantages obtainable.

At ¾d. per unit, and with apparatus turned out in quantity, nothing should in the future stop great developments. It must not be forgotten that the amount of power and heat which houses can absorb must be throughout the country more than that taken in industrial works, and an enormous field is thrown open for development.

The table below is an estimate of the energy which houses of various rateable values might be likely to consume if electrical energy were used throughout the house for all purposes—*i.e.*, for cooking, heating, and power work; the third column gives the equivalent value in B.H.P. of a motor running factory hours all the year round.

TABLE VI.

Rateable Value of House.	Probable Units per Annum Consumption.	Equivalent Brake Horse Power of Motor working Factory Hours Full Load (approximately).
£ 20	5,500	3
30	8,500	4
40	12,200	6
50	15,000	7½
60	18,400	9
70	21,500	11
100	26,000	13

These figures are, of course, open to criticism as requirements alter, and the rateable value for a given size of house varies considerably in different localities.

A "telephone" system of supply for all purposes with one service, one meter, and one set of wiring, giving an average of, say, 4d. per unit for lighting and ¾d. for power, is not too much to hope for when the value of this class of load is realised.

As regards the future: It is a practical certainty that all cooking operations besides heating and motive power work in a house will eventually be done by the application of electrical power, the question "how long" depending on two main factors, viz., the supply authorities and the manufacturers. The former are asked for a price of energy which is on a par with its other competitors, the latter for apparatus

which is of such a price that it will appeal to the great middle class and which is simple and convenient to operate and will stand rough usage. It is highly probable that flexible wires and plugs will eventually have to go; on the other hand, self-containing apparatus, *i.e.*, one electrical heater for each vessel, is likely to be standard practice rather than the hot-plate system, unless the power price is very low indeed.

The author is well aware that there are some supply engineers who consider loads of the domestic description not worth troubling about, but it must be borne in mind that the majority of small industrial power is now absorbed by the supply authorities where their mains run, and big power loads to be obtained at all have to be taken on at prices lower than those which we are considering, and even then there is hesitation; it therefore behoves us to make a serious endeavour to enter this domestic supply field. Needless to say, it will take some years to be firmly established, as a new generation requires to be educated in this direction. Pressure should be brought to bear to have installed apparatus in higher grade Council schools and in all private cookery schools with this object in view.

A deferred payment system for apparatus will also be necessary to compete successfully with the gas interest, and intelligent canvassing is essential to success.

APPENDIX.

PRICE OF DOMESTIC POWER (CURRENT AT JULY, 1910).

Authority.	Price per Unit (Pence).	Authority.	Price per Unit (Pence).
Accrington	1, proposed ¾	Brighton	1½ and 1
Acton, W.	1¾	Bristol	1½
Altrincham	2¼	B.I. (Prescot)	1
Ashton-under-Lyne	1½ to 0·6	Burton-on-Trent	3 and 1 and 2 to 1¼
Ayr	2	Bury	1
Barnes (Mortlake, S.W.)	1¼	Bury St. Edmunds	3 to 2¼
Barnsley	1½ to 1	Cambridge	1½
Barrow-in-Furness	2 to 1½	Carlisle	2
Bath	1¾	Caterham	1½
Batley	1	Charing Cross	1
Battersea	1	Cheltenham	2
Bedford	1	Chester	1
Belfast	2¼ to 1	Chesterfield	1½ to 1
Bermondsey	1⅛	Chiswick, W.	2
Birkenhead	1¼ to 1	Colwyn Bay	3
Birmingham	1·35 to 1·10	Coventry	1½ to 1
Blackpool	1	Croydon	1½
Bolton	2 to 1 less 10 per cent.	Darlington	1½ to ¾
Bootle	2 to 1	Derby	1¼
Bournemouth	2	Devonport	1¾
Bradford	Proposed New Rate ½	Dewsbury	2½ and 1
		Doncaster	2 to 1½

Authority.	Price per Unit (Pence).
Dorking	1½
Dover	2½
Dundee	1½
Ealing, W.	1½
Eastbourne	2½ to 1
Eccles	3 and ¾
Finchley	2 and 1
Frome	Fixed charge plus 1½ unit
Gillingham	1
Govan	1
Grimsby	1
Guildford	1½
Hackney, N.E.	1½
Halifax	2
Hammersmith	1½ and disc
Hampstead, N.W.	1
Handsworth (Staffs.)	1
Hanley	1
Hastings	2
Heckmondwike	1
Hereford	1½ and 5 per cent. disc
Horsham	3 and 1½
Huddersfield	2 and 1
Hull	2 and 1
Ilford	2 to 1
Ilkeston	1½
Ipswich	2 to 1½
Kettering	2 to 1
Kidderminster	1½
Kilmarnock	1¼
King's Lynn	1½
Kingston-on-Thames	1½
Kirkcaldy	2¼ to ¾
Leeds	1½
Leith	1½
Leyton (Leytonstone, E.)	1½
Lincoln	1
Liverpool	2 to 1
Llandudno	2
Loughborough	1
Lowestoft	2 to 1
Luton	½
Maidenhead	2
Maidstone	1
Manchester	1
Mansfield	1
Metropolitan Electric Supply Company	3 and ¾
Minehead	1
Newcastle-on-Tyne	1½
New Brighton	1½
Newport	1¼
Nottingham	1¼
Nuneaton	1
Paisley	1½
Peterborough	1½
Plymouth	1¾ and 1½
Pontypridd	1½ and 1
Rathmines	1½
Richmond	1
Rhyl	4 and 2
St. Anne's-on-Sea	2 and 1½
St. Marylebone	1
St. Pancras, N.W.	1
Salford	1½ and 1
Scarborough	1
Sheffield	1
Shoreditch	1
Smithfield Markets, E.C.	1½
Southampton	½
Southend-on-Sea	1½
South Shields	2
Southwark	1
Stafford	2½
Stalybridge	1 less 2½ per cent.
Stepney	1
Stockton-on-Tees	2 to 1⅛
Stockport	1¼
Stoke Newington	5 and 1
Stowmarket	3
Stretford (Manchester)	1½
Swansea	2 and 1½
Tunbridge Wells	2½
Twickenham	½ per unit
Uxbridge	2½
Wakefield	1
Walthamstow	2 and 1
Warrington	2
Wednesbury	1
West Bromwich	1½ to 1
Weybridge	2
Weymouth	2½
Whitby	1 per unit
Wigan	Propose 1
Willesden, N.W.	1½
Wimbledon	1
Wolverhampton	1
Worksop	1
Wrexham	1

Discussion before the Manchester Local Section.

Mr. Watson.

Mr. S. J. Watson: The paper is not an easy one to discuss, but it appears to me that this question of electrical cooking can be discussed broadly under two heads: (1) The use of self-contained apparatus, and (2) the use of apparatus of the hot-plate type. A good deal can be said on both sides, but to my mind the balance, in spite of its somewhat lower efficiency, lies with the hot-plate type, because the apparatus is self-contained, requires no loose flexibles or plugs, and we are able to use the ordinary commercial pots and pans in connection therewith, and the price of a complete outfit must, I think, be appreciably the cheaper of the two. In regard to ovens, the design which the author has got out certainly appears excellent. Undoubtedly the principal point to be considered in designing an oven is to obtain a thorough circulation of the heat so that the temperature throughout will be kept nearly constant, and this certainly appears to be the case in Mr. Gray's design. I was very interested in the method that Mr. Gray suggests of obtaining regulation by means of running a water heater more or less in series with the different apparatus. In considering the question of heating generally, one is bound to approach the matter from the point of view of using electricity supply for all domestic heating and cooking purposes. Not very much progress will be made unless electricity can satisfactorily compete against coal or gas for such purposes, and one of the first requirements in domestic work is an ample and regular supply of hot water; consequently the water heater would always be available for the purpose of regulating the supply to other utensils. It is, I think, absolutely necessary that regulation should be provided. In the case of an oven, for instance, it appears to me to be absolutely essential, otherwise the cooking will be done much too fast, and it should be possible to use two or three different heats. The arrangement which the author shows for taking up the slack of flexibles is a neat one, but I feel doubtful whether it is desirable to use flexible wire in positions where it may be alternatively exposed to heat and cold, dampness and dryness. With regard to the charges for supply, I think Mr. Gray has very properly mentioned the question of devising suitable tariffs to assist the development of heating apparatus. The Appendix shows that the prices charged by different towns varies from ½d. to 3d. per unit. The difference between ½d. and 3d. does not appear to be a great deal, but it certainly seems absurd that one supply authority should charge £6 for a commodity which another authority is willing to supply for £1. I cordially agree with the rateable value system of charging mentioned by the author, and believe this system will be used to a much larger extent in the future.

Mr. Cridge.

Mr. A. J. Cridge: I am interested in the subject of electrical heating and cooking, which we propose to push forward in Sheffield as soon as we are sure that we have got hold of the right apparatus—one which will compete with gas and coal-fire cooking. The author men-

tions several points which he calls "essentials," one of them being the efficiency of the apparatus. If you put electricity into any piece of stationary apparatus in which it is absorbed, it all appears as heat either radiant or convective. The apparatus gets rid of its heat by radiation, convection, and conduction. Radiation is itself a form of energy which is turned into heat when it falls upon opaque substances. Loss of heat by conduction is minimised as far as possible in the construction of the stove. Convection currents are set up in the air, and heat is taken away by them; thus the efficiency of any apparatus from this point of view is 100 per cent. What the author means by efficiency is the efficacy of the apparatus in putting its heat where it is wanted. The term "efficiency" is misused in this case. On page 250 the author makes use of the expression "crude heat." It is very necessary to remember that the heat obtained from gas is not always, nor is all of it, available for immediate use. Tests of calorific value are liable to be misleading if this fact is ignored. On page 252 in the table, reference is made to a point at which the efficiency of gas heating begins to decrease. We know that the top part of a Bunsen flame is the hottest. If you admit too much gas or too much air you cool the flame, and so waste gas. On page 256 the author says that 3 k.w. is the energy required to heat up the oven. That is too much. I would like to know exactly what oven he is referring to, because I know of one which only requires 1·5 k.w. On page 257 he refers to the use of a thermometer. I must say I think this is a little too academic. No one ever uses a thermometer, and little refinements of this sort are not likely to be useful. With an electric oven in which we always know the energy passing by means of the switching arrangements, it would seem to be less necessary than usual. Moreover, the temperature will not be the same in every part of any oven, whether electric, or coal, or gas. Some foods require to be cooked by radiant heat. Toast, for instance, or any food which is required to have a brown surface with an interior not quite so well done, is best obtained with radiant heat. It is not purely a question of the right cooking temperature. On page 259 there is a reference to the fineness of regulation obtainable with gas taps. In actual practice this generally resolves itself into about three heats—full, about half-full, and something a little less than that. If the gas is only just alight it is liable to be blown out by the draught made in moving about, or opening or closing a door; and gas taps sometimes stiffen, when regulating is difficult. The telephone system of charging is a good system if it is made compulsory to use electricity throughout their premises. The very fact, however, that the fixed charge is based upon the size of the installation, prevents people from installing electric light as freely as they otherwise might. In the last paragraph of the paper the author writes: "A deferred payment system for apparatus will also be necessary to compete successfully with the gas interest." I quite agree. But if you want to hire a gas stove, you can get it either from the manufacturers or from the gas supply authority. Let manufacturers of electrical cooking apparatus

Mr. Cridge

Mr. Cridge. have the courage of their convictions. If they are confident of the excellence of the apparatus, let them hire it out. Electric supply departments are in many cases hugely over-capitalised as it is, and there is no money to spare for hire-purchase business. It has been suggested to me that in order to gauge the usefulness of a cooker we should measure the time required to perform a certain operation, such as heating water, and that cooker which did the work most quickly would be the best. That is not quite correct. We do not always want to consider the man that gets up late and has to bustle through his breakfast. Some of us like our food cooked nicely. In a coal oven the hot gases pass up one side and over the top. We are getting nearer to the coal-fire practice when we use hot plates, especially one at the bottom and one at the top. If the heating elements are at the sides, food placed near them is liable to be scorched. It is cool at the bottom of the oven, and food placed there becomes what is called "sad." The top of the oven is the only place where the cooking is satisfactory. It is not right to proceed on gas lines in this matter. Heavy stuff, lagged, black, and cumbrous is not so satisfactory as the bright, shiny, thin-walled type. You are all aware, of course, that I refer to the "Tricity" oven. In that oven a plain lunch for twelve people can be cooked for 3d. or less, while with another type of oven, in which the gas designs have been copied, lunch for three people costs 8d. to cook. Radiation is going on all the time from the black surface, and we must stand a clothes-horse round it to get any benefit from the heat at all. The cost of cooking the second lunch should not have been more than 3d.—was not, in fact, more than 3d. The other 5d. was spent on airing clothes.

Mr. Grogan. Mr. F. S. GROGAN: The author in this paper mentions that he would like to bring out some underlying factor which is retarding the use of electric cooking. I have been engaged on this question for the last four years, and have come to the conclusion that we are in the same position as the gas companies some fifteen years ago. They had to educate the public to use gas stoves, and we have to do the same with electric stoves. In a few isolated cases flats in London have been built without the kitchen range, and provision made for a gas stove; now we have to get architects and builders to provide electric cookers. Of course I am taking for granted we have got a satisfactory cooker and a reliable one—a cooker which is cheap in first cost and running costs. I maintain that we have produced that already in the "Tricity" cooker. It has been stated that the method of hiring out cookers should be started by the manufacturer. This policy is wrong, because a manufacturer could only hire out at rates which would pay him on a commercial basis, and these rates would greatly exceed the 3s. per quarter charged for gas stoves. The electricity supply authority can afford to hire at a nominal rate and allow, say, ⅛th of a penny extra on the price per unit in order to get the money back on the sale of the current. Therefore I advocate keeping up the price of the current, charging a nominal hiring rental on a reliable cooker more on a

Mr. Grogan.

par with rentals of gas stoves. That is the way to encourage the public and bring in revenue from electric cooking. There will come a time when the distributing systems throughout the whole of the country will not be nearly large enough to cope with the tremendous demand for electric cooking which we hope to obtain in the future. There will therefore be a great capital outlay on cables and distribution generally. This must be kept in mind when fixing the price per unit for cooking and power loads.

The methods of publicity could be vastly improved to encourage electric cooking. The proper way is to give demonstrations throughout the country, and if the supply authorities will only help the manufacturers, and provide showrooms where actual cooking operations are carried out daily, that is the best way to popularise electric cooking. I have had exhaustive tests made of "Tricity" apparatus, and I can state definitely that when the price is 1d. per unit and the price of gas 2s. 6d. per 1,000 cub. ft., the comparative costs for cooking by the two methods are equal. There is a small balance in favour of electricity at those prices, but you may take it that they are practically equal. From the manufacturer's point of view I should feel greatly alarmed at the author's deductions in this paper if the figures shown for gas costs were obtained in practice. I refer now to what he calls Section A. If you refer to Tables II. and IV. you will find that the cost with gas is pretty well half the cost of electricity even when he has taken the figure I have taken for gas, 2s. 6d. per 1,000 cub. ft. and only ¾d. per unit. I will endeavour to show you why these figures are wrong. In Table II., if we refer to column 2, we find the gas only varies from 3 to 8 cub. ft. per hour. That must have been a very small burner indeed. In order to make this comparative test you must take the commercial gas cooker. I have taken many tests on gas cookers. For instance, during 1908 I took the consumptions on the various burners of a Fletcher gas stove hired at 3s. per quarter. It had three boiling rings, one griller, and an oven, and the consumption of gas per hour through those ranged from 8 ft. per hour on the smallest simmering ring up to 50 ft. per hour on the griller, and the oven also consumed 50 ft. per hour. In that case the results I obtained were 0·048d. per lb. of water at the lower rate of consumption, and 0·055d. per lb. of water at the 50 ft. per hour consumption. These figures are twice as great as those given by the author in Table II., column 5. This brings the efficiency of the gas cooking over all to about 11½ per cent. By efficiency I mean the ratio of the number of B.Th.U. of heat actually put into the boiled water to the theoretical heat units that could be obtained by complete combustion of the gas consumed on a basis of 685 B.Th.U. per cubic foot of gas.

The gas costs I have obtained on a practical gas stove are higher than the author shows in his Table IV., viz., 0·041d. for electricity. According to that we are rather better off in the electric cooking (Class A) than in gas cooking. I have taken other tests to confirm these, so I am perfectly certain of my results. Just to emphasise that

Mr. Grogan. the author's gas results are unpractical, if we look at Table II. we can deduce that the time taken to boil 1¼ lbs. of water (*i.e.*, 1 pint) is 21·3 minutes on the first test, 15·6 minutes on the second test, and 7·5 minutes on the third test. You will see I have just added 25 per cent. to the time given to boil 1 lb. of water. Nobody would think of putting a 5-pint kettle to boil water and expect it to take 20 minutes per pint—*i.e.*, 1 hour 20 minutes if full. This comparison at such a slow rate of boiling is most favourable to gas. The average time in practice is about 4 minutes per pint of water. I would also point out that the most favourable results are not shown for electricity in Table IV. On the table here is a "Tricity" urn which is heated in the same way as all the other utensils, by placing on a hot-plate. This urn contains 16 pints of water, and from independent tests which were taken at Bradford, I understand that an efficiency of 80 per cent. was obtained when starting everything from cold. I would therefore strongly advocate the general use of the hot-plate system in preference to all others. With regard to the second class of the author's tests, we are told on page 254 that the heating up from cold is not included in the baking tests given in Table V. I maintain that the power taken for heating up the oven from cold should be included in the total power used when comparing electric ovens with gas ovens, and this is the only part of the paper which is at all favourable to electricity. If a lagged oven was used for these baking tests, I am certain that one taking 3 k.w. could not have been raised to a temperature sufficiently high for baking bread under less than half an hour—*i.e.*, the power used would have been 1½ units, which at a 1d. a unit would cost 1½d. The lagged oven, therefore, in my opinion, is very expensive to operate, and the total first cost on such an electrical outfit as is shown on the table, together with all the self-contained utensils and electrical switch-board on the telephone jack principle, is out of all proportion to what the public are prepared to pay.

On the left of the lecture table is a duplex cooker, which, together with one or two extension cookers, will entirely replace a kitchen range, and the total first cost for supplanting a kitchen range with this apparatus, including all utensils, is only £10 to £12. I would also direct your attention to the "Tricity" oven in the background, which is used in conjunction with this hot-plate system. It is placed over one-half of the duplex cooker, and one of the extension cookers connected to the wall plug at the end of the duplex is placed on top of the oven with hot-plate reversed, so that it projects inside. The oven is not lagged in any way, and a very high efficiency is obtained by merely keeping its thin walls brightly polished on the outside. There are practically no radiation losses from this oven when in operation, and the time taken to heat it up to baking temperature with a consumption of only 1,600 watts (*i.e.*, 800 watts on the bottom hot-plate and 800 watts on the top hot-plate) is only 15 to 20 minutes, the total cost, at 1d. a unit for the heating of the oven, being only ½d. I should like to draw attention to the difference between boiling water in small

quantities for cooking purposes and boiling water in large quantities, viz., several gallons per hour, such as is required in a hot-water system throughout the household for bath purposes and washing up. In the following table I reduce everything to an equivalent number of B.Th.U. so as to show the marked difference between boiling water under these two conditions with electrical energy. I will assume for the basis of comparison that— Mr. Grogan.

Coke at 20s. per ton will give 12,000 B.Th.U. per lb.
Gas at 2s. 6d. per 1,000 cub. ft. will give 685 B.Th.U. per cub. ft.

Note.—Although water-gas is being largely added to the ordinary coal-gas, and the illuminating power of the resulting gas is considerably less, the calorific value in many cases falls but little below the original coal-gas.

Electricity at 1d. a unit will produce 3,455 B.Th.U.

	Comparison of Theoretical B.Th.U. obtainable from 1d. Worth of Each, assuming 100 per cent. Efficiency.	For Cooking Purposes.		For Bath and Hot Water Supply.	
		Efficiency obtained in Practice.	Useful B.Th.U. obtained from 1d. Worth of Each.	Efficiency obtained in Practice.	Useful B.Th.U. obtained from 1d. Worth of Each.
		Per Cent.		Per Cent.	
Coke ...	112,000	2	2,240	$62\frac{2}{3}$ (with "Ideal" stove)	74,667
Gas	22,833	12	2,736	50 (with gas geyser)	11,416
Electricity...	3,455	80	2,764	90	3,109

You will see from this table that although it is possible to compete favourably when using electricity for cooking purposes, owing to the great inefficiency of other apparatus, we are beaten hopelessly when attempting to boil water in bulk, owing to the very high efficiencies which are obtained with coke and gas apparatus. I could easily design an electric boiler for doing such work with 90 per cent. efficiency, but what manufacturer would attempt to put such apparatus on the market with these figures and tremendous odds staring him in the face?

Mr. J. FRITH: I have had one or two experiments made with gas-cooking in order to make sure that the basis of comparison used in the paper is correct; these experiments practically uphold the author's figures; for instance, 1 lb. of water was brought to boiling in 4 minutes, using 1·2 cub. ft. of gas, and evaporated in 19 minutes, using 4·35 ft.; Mr. Frith.

Mr. Frith. 8 lbs. of bread were baked in a gas oven in 50 minutes, using 26 cub. ft. of gas. Returning to the paper, I think that which militates most against electric cooking is the high price of the apparatus; many would install it as an experiment were it not for the large capital outlay involved. The reliability of the apparatus itself is, as far as my experience goes, good, but the flexible connections give a great deal of trouble. The efficiency is excellent; 81 per cent. for warming up and 91 per cent. for running can scarcely be improved upon. I was surprised to learn how well the hot-plate system compared with the self-contained, even when earthenware vessels were used. Speaking of regulation, I cannot understand why rheostatic control has not been mentioned. In general, when electric-cooking apparatus has to be "turned down" at all, the power is reduced to a small fraction of its full value, and the loss in the resistance is therefore negligible. If thought worth while, the regulating resistance could be inserted into the hot-water apparatus, attaining the same end as that mentioned in the paper combined with much better and simpler control. With regard to earthing, with large stationary apparatus there is no difficulty, but with small portable utensils fed from a supply with one wire earthed why should not the terminal connected to this wire be connected straight to the body of the kettle, etc.? This would entirely get over the risk of shock, and the right connection could be ensured by the use of either concentric or T plugs. The oven illustrated in the paper does not appeal to me, for two reasons. First, I believe that most cooks would prefer, if the top and bottom temperatures did differ, that the bottom should be slightly hotter than the top; but the second fault is, to my mind, more serious; it is, that the hottest air is fed first against the walls of the oven and parts with a good deal of its heat to them before it comes in contact with the food at all. How much heat is lost in this way can be felt on standing by one of these ovens at work. The walls of the oven should combine the properties, as far as possible, of great heat insulation and low heat capacity, and surely the outside should be bright. There is a great future for a vacuum-jacketed oven on the "Thermos" principle. I cannot quite follow Table VI. The electricity in the middle column, at the mixed rate of 4d. for lighting and ¾d. for power mentioned below, would cost as much as the rent of the house.

Mr. Hurst. Mr. T. H. Hurst: There are a few points which have not yet been taken up. One of the chief features of electric cooking is the even rate of heating in all parts of the oven. Under such a condition cooking is reduced to a mere mechanical process and a question of time. The object to be cooked is placed in the oven for a certain time, and that is the end of it. There is no risk in the oven getting too hot or too cold by reason of too big a fire or want of attention in keeping it up. There is no dirt and things are sure to be clean. We have had visible proof of how many articles one cook can look after at the same time, and it appears that this is one of the solutions of the domestic servant problem, because, if we take a case where several servants are employed, it is possible to reduce the number under such conditions.

Mr. Hurst.

I would like to ask the author if he can give an idea of the working and fusing heats of the material employed in the heaters, because we could then give an opinion of the reliability of the instrument; and reliability is what we want in order to convince the consumer that he is getting a good thing for his money. The telephone system appears to be a very nice arrangement, but to guard against accident and damage by water a solid inlaid system should be satisfactory.

Mr. Peck.

Mr. J. S. PECK: I was in America last summer and saw many different types of cooking apparatus; the construction of some of them was very ingenious. I was advised by one manufacturer to have nothing to do with cooking apparatus designed for 200 volts or higher. He said the higher voltage apparatus was in general very unsatisfactory. I should like to ask the author whether his experience bears this out. I should also like to ask what success is being met with in Accrington in introducing the use of electricity for cooking purposes.

Mr. Cooper.

Mr. W. R. COOPER (*communicated*): In considering the question of the supply of hot water for domestic purposes, I think there is a tendency to underestimate the quantity that is required. I do not know of any figures on this point, but judging from my own observations I should think the amount would run from 10 to 15 gallons or more per person per day. It is impracticable to heat the water rapidly by electrical means, because this involves heavy currents, and these cannot be supplied cheaply, apart from which there is the objection that heavy wiring would be necessary. In the "Therol" heater this difficulty is obviated in an ingenious way, and the method should prove effectual for small supplies. For large supplies there seems no reason why thermal storage should not be resorted to. For example, a tank holding 100 gallons is not particularly large, and it might be heated continuously by a current equivalent to the mean demand of heat. In the early morning the temperature would be a maximum, and a large amount of water would be required—say, one-quarter of the capacity; the demand would then slacken off for a time and the temperature would rise slowly. In the evening there would be another heavy demand, but during the night the temperature would again rise. The fluctuations in temperature would not be inconvenient for household purposes, and for such uses the temperature need not be anywhere near the boiling-point. If current were supplied continuously to such appliances, which would be permanently connected to the mains without a meter in the circuit, a constant load would be obtained and could be supplied at a very low rate, or a fixed charge per quarter. Probably ½d. per unit would meet the case. It might be necessary to include a thermal cut-out, but this should not prove an insuperable difficulty.

Mr. Thomas.

Mr. EUSTACE THOMAS: It is amusing to think that we should have met here to discuss cooking and appliances for cooking, when probably there is scarcely any one present who knows enough to cook a meal of even a very simple character. If a cook asks us how to cook electrically a meal consisting of soup, fish, joint, game, sauces, vegetables, sweets, savouries, etc., heating and keeping warm plates,

Mr. Thomas. dishes, etc., we should probably be at a loss to answer him. Mr. Gray was very well advised in showing practically the preparation of such dishes, and such demonstrations should be made as frequently as possible as an education to ourselves in the requirements that have to be provided for. In particular, it is extremely necessary that ample provision should be made for keeping a number of dishes warm without overheating or spoiling the food; and our electrical appliances and the outfits that are offered appear at present especially crude in this respect. Electrical cooking in general cannot possibly hope to make its way, at prices for energy that will rule for a long time to come, by superior cheapness. Gas appliances can be greatly improved, and will be, so soon as electrical cooking shows any signs of being a serious competitor. At present there is great waste in the use of gas, which improves our chance; but much of this can be got rid of when skilled attention is directed to design. Electrical cooking therefore must cater by its superior convenience and cleanliness and by more skilfully providing for the requirements of the cook as regards such matters as keeping food warm, etc. In this respect there is very great scope, and the present state of development, as stated before, is characterised by great crudeness. Self-contained vessels are very expensive, and an impartial examination of them must make us wonder how they will fare when the ordinary domestic handles them and attempts to wash and clean them. Think of sluicing an electric saucepan or frying pan as one does ordinary utensils. Moreover, the contact-making devices for attachment of wires, etc., are liable to damage with the quick and rough handling to which they are likely to be subjected. Then, too, both these and the hot plates which have been devised to take the place of the gas-ring are far inferior to the gas-ring in heat regulation for simmering, keeping warm, etc. Many of the ovens and the vessels for use with hot plates are flimsy tin affairs. Tin cooking vessels are not looked upon in the ordinary good household as very high class, and in hotels, etc., are little used, expensive copper vessels being very largely employed. So at the outset our gear is flimsy and cheap looking to the better class householders, to whom I think we have to look for our custom when we are trying to get all the cooking of a house done by electricity. But although improved gas appliances can entirely beat us on cost, I do not think we need be discouraged if we make for superior convenience and perfection, and improve our appliances accordingly. We may take heart when we remember that the whole of the present electric lighting industry, in which many millions of pounds are invested, was built up when electric lighting was much more expensive than gas lighting. But it was adopted among those who were comfortably off and could study convenience and advantage and not cost alone. So history seems to indicate that the correct policy is to improve and make perfect our appliances rather than to make them too cheap. As soon as we can work better by electricity than by gas or fires we shall get a rapidly increasing market. One speaker has criticised the use of a thermometer in ovens. Surely

Mr. Thomas.

it is obvious that it is better to know absolutely when you are at the temperature that is right for cooking meat or pastry or what not, than to try and judge by the old-fashioned methods of feeling the handle of the oven or opening the door for a moment and trying to judge by the waft of hot air thrown out. And in actual practice, when a cook has had a few days' experience with an electric oven provided with a thermometer she finds it such an immense aid to efficiency that she feels lost when deprived of it. Moreover, the most modern bakers' and pastry cooks' ovens are now provided with an equivalent appliance. It is one of the points that will help us to sell electrical cooking outfits. The gas-ring at present has much greater range of regulation than the hot plate, and manipulation of the tap has an instantaneous and visible effect, while it is instantaneously brought to full heating, or put out. Hot plates, at present, are slow to heat up and cool down, they are difficult to regulate, the effect of regulation is not at once visible, and they are more liable to damage. For such heating we are behind gas, although it is quite possible that very soon these disadvantages may be largely removed. But in the oven we have already many advantages over gas. To argue that ovens should be built of tinned iron without lagging is as retrograde as to try to advise a station engineer to cover his steam pipes with bright tinned iron instead of lagging them. We want efficiency. So also in the oven that Mr. Gray has developed, an immense move forward has been made in obtaining an almost perfectly uniform temperature and equal rate of cooking at all parts and on all sides. In a little while this will be appreciated and will do perhaps more than anything to enable electric cooking to get a footing. At present we are accustomed to ovens in which the food is bathed in the products of combustion from more or less foul gas. And we take it as a matter of course to open the door several times and turn the food about to make it cook evenly. And this causes one of the great difficulties that makes good cooks so scarce. But with Mr. Gray's oven: (1) By the thermometer we can get to the right temperature for any kind of food and maintain it; (2) we can look in at the window and watch the progress of the cooking without opening the door; (3) we cook uniformly without turning the food about; (4) we can flash or seal at a high temperature to start with, and then lower to a suitable cooking temperature to continue; (5) because we are cooking uniformly and at the highest suitable temperature we cook more quickly; and (6) because the oven cooks quickly and is efficiently lagged it uses less energy and is already often cheaper than gas. Every other oven I know of gives too much top, or bottom, or side heat, whether fire, gas, or electrically heated. Mr. Gray's oven is a real advance in the right direction, and it is already possible to go to the customer and honestly to tell him that the appliance is more perfect in all respects than gas ovens and worth the investment of his money. But can we say that of hot plates, etc., as yet? I would urge before everything, with all the emphasis that can possibly be given, that perfection in the appliances is the essential to be striven for, and

Mr. Thomas. that to offer cheap, flimsy stuff will retard the great ultimate development instead of helping it, and is altogether a wrong policy. No one wishes to know that it is possible to cook by electricity; they wish to cook better by electricity and with more comfort, convenience, and cleanliness. In conclusion, a case of great interest has come before me. Many people are prepared to furnish houses, and even to build them, and generally to lay out considerable sums, for their enjoyment and comfort, without expecting monetary interest on the investment. In this way immense numbers of private electric light plants have been laid down—chiefly, of course, in the country. But after laying out a lot of capital in this way a disproportionate amount of importance is often laid on the cost of running being kept low. Now we have recently gone into the conditions for providing in a house, shortly to be built, for heating, lighting, and cooking by electricity; a suction gas plant being laid down. It is astonishing to find that the yearly cost of anthracite fuel for such a plant is little, if anything, more than the cost usually incurred in such houses for house and kitchen coal and for lighting by gas. This is well worth pondering over.

Mr. Gray. Mr. H. GRAY (*in reply*): Mr. Watson seems to prefer the use of hot-plates to self-contained vessels. I think it is a fact that all of us would adopt the hot-plate principle if the question of efficiency did not come in; the hot-plate is unquestionably less efficient than the self-contained vessel. The lower the price of power, the more, of course, does the hot-plate become a serious competitor of the self-contained vessel.

In reply to Mr. Cridge, I do not think the use of thermometers with cooking ovens is at all academic. They are now being introduced on coal and gas ovens, and they are in my mind now a practical necessity for high-class cooking. As stated in the paper, with a well-built oven it is impossible to tell the temperature of the inside by feeling any external part, and the door must not be opened more than necessary, in order to economise power. When the gas-makers realise the poor efficiency they now have with gas ovens they will wake up and bring improvements along, which will be commensurate with that of the gas mantle over the batswing burner, and it needs every effort on our part to bring in successful competitive material. With regard to hot-plate regulation, I still consider two heats are not sufficient, and that a considerable number of gradings is necessary.

In reply to Mr. Grogan, the gas burner used in the tests was a standard cooking gas-ring. I am very much surprised at the consumption instanced by him of the gas-rings, etc., on the top of a cooker taking 8 to 50 ft. per hour; 40 ft. is a big consumption for a gas oven, and the smaller appliances usually take considerably less. I am pleased to hear that his hot-plate efficiencies attain 80 per cent. This high figure does not correspond to the tests made on this lecture table to-night, or to my own tests with hot plates.

In reply to Mr. Frith, the use of external rheostatic control for cutting down the heat on self-contained vessels and hot-plates is quite likely to be of advantage, owing to the simplicity where power is

reasonably cheap. Where power is high in price the lost heat—which, of course, is dissipated into the air—would quite likely amount to a serious amount. With crude gas heat costing four times that of electric heat we have to economise in all reasonable ways. As to the suggestion of the earthing of the shell of pots and pans to the earthed main of the system, supply engineers do not reckon or like to have more than one definite earth-point on their system. An arrangement of this sort would cause great trouble to mains engineers. The providing of an entire glass door to ovens is, I think, impracticable, as it would be expensive to replace if broken, and is likely to be easily cracked by hot grease, etc., striking it. Quartz glass would be a suitable material to overcome this difficulty, but it is not transparent enough. As regards Table VI. in the paper, the unit consumption for various sizes of house mentioned are the total units which could be used in a house; but few consumers would go in for a complete installation unless the price of power was down to or below ½d. per unit. In this connection I may mention a house which is being built without chimneys, and which has three sitting-rooms, usual offices, and four bedrooms, in which electrical power is to be used for cooking, heating, motor work, etc., to the exclusion of coal and gas. The house is outside any public electric supply area, and a suction-gas plant of 12½ H.P. is being employed with a battery. The estimate of units to be consumed for that house is 16,000 units per annum, and the power will come below ¼d. per unit at the terminals of the appliances. The running cost, thus, on these units is less than £20 per year. Mr. Gray.

In reply to Mr. Peck, regarding the reliability of high-voltage cooking apparatus we do not nowadays often find trouble due to bad insulation on 230 volts. The electrical manufacturing industries in England have been used to this pressure for more than twelve years now, and have overcome the difficulties encountered. I can quite imagine, however, that in America—where they are used to 100 volts—the use of apparatus at double this pressure would give them considerable trouble at first. We find that our consumers, who use good cooking apparatus, are quite satisfied with the performance of the apparatus, and their accounts for power are not abnormal; but the heating of rooms by electric radiators is not as economical an application as that of cooking by electricity.

SOME CONSIDERATIONS RELATING TO THE PARALLEL WORKING OF ALTERNATORS.

By JAMES R. BARR, Associate Member.

(*Paper received October* 11, 1910, *read before the* GLASGOW LOCAL SECTION *on February* 14, 1911.)

(This paper was read by Professor F. G. BAILY, after the death of the author, which took place on December 6, 1910.)

LIST OF SYMBOLS.

D = diameter of gyration in metres.
E = rated voltage of alternator.
g = acceleration due to gravity = 98·1 in kg.-metre units.
I_0 = short-circuit current.
I_s = synchronising current.
K_g = mass of rotating parts in kilogrammes.
M = constant mean torque of engine.
M_s = synchronising torque.
m_s = synchronising torque for electrical degree of displacement.
$m_{max.}$ = amplitude value of oscillating torque.
n_c = number of impulses per revolution.
p = number of pole pairs.
q = reaction quotient.
R = revolutions per minute.
$S^{max.}$ = amplitude value of displacement.
W_s = synchronising power.
T_1 = periodic time of free oscillation.
T_2 = periodic time of a forced oscillation.
$T_{crit.}$ = critical periodic time of an oscillation.
z_a = armature impedance.
a = displacement of field system in electrical degrees.
a_1 = initial displacement due to forced oscillations.
a_0 = final displacement.
a_2 = angle of damping.
$\gamma_{max.}$ = amplitude value of variable acceleration.
δ = cyclic irregularity.
ϵ = coefficient of insensibility.
θ = displacement in space degrees.
ω = angular velocity.
$\Sigma m r^2$ = moment of inertia of rotating parts.

When a number of alternators, designed for the same frequency

and equal terminal voltages, are required to supply energy to a given network, they must, of course, be connected in parallel, and owing to the inter-reactions between the prime mover and generator, the problem is somewhat more complex than that which presents itself in the case of working direct-current generators in parallel. In this paper it is proposed to discuss the various causes that lead to unstable working, and to examine what precautions must be taken in the design of an alternator in order that it may work satisfactorily in parallel with other sets.

Effect of Engine Governor on Distribution of Load.—In a steam engine the function of the governor is to regulate the amount of steam admitted to the cylinders, so that for considerable fluctuations in load the speed is maintained within certain narrow limits. This regulation is generally affected by throttling the steam, and thereby varying the pressure in the cylinders. At the lower limit of speed the centrifugal force of the governor balls will not be sufficient to move them out against the controlling springs, so that there is no throttling and the

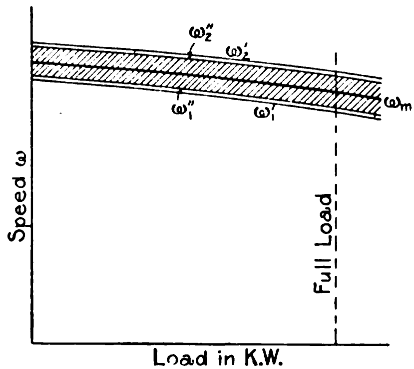


FIG. 1.

steam pressure in the cylinders is a maximum. At a somewhat higher speed the balls move out to a position where the greater centrifugal force is again balanced by the extended springs. As the position of the governor balls alters they are made to operate some mechanism which adjusts the position of the throttle valve, and thereby reduces the mean pressure in the cylinders. Should the speed go on increasing the balls will ultimately move out to their fullest extent, in which case the supply of steam is entirely cut off. For each position of the governor there is therefore a definite speed, and if the mean speed of the engine, as controlled by the governor, be plotted as a function of the load on the alternator, a curve such as ω_m in Fig. 1 will be obtained. The difference between the speeds corresponding to no load and full load—*i.e.*, for minimum and maximum steam pressures—is called the drop or regulation of the governor, and this varies, according to the type of governor, from 3 to 6 per cent. of the no-load speed.

When several alternators are worked on the same busbars the amount of power supplied to the network by each machine depends almost entirely upon the angle of advance ϕ of its induced voltage E_t with respect to the busbar voltage E. The greater the vector difference between E_t and E, the greater will be the voltage available for overcoming the armature impedance, and hence the greater will be the current which the armature can supply. The magnitude of the angle ϕ is dependent only on the load on the alternator, and if the speed of the engine alters with the load it can be regulated by the governor.

During each revolution of a reciprocating engine the angular velocity varies between two limits, ω_1 and ω_2; and if—

$$\omega_m = \frac{\omega_1 + \omega_2}{2}$$

denote the mean angular velocity, the extent of this speed variation can be expressed thus—

$$\text{Cyclic irregularity} = \delta = \frac{\omega_1 - \omega_2}{\omega_m}.$$

With a very sensitive governor the fluctuations in the angular velocity of the prime mover would set up periodic oscillations of the governor and so cause hunting. To avoid such a tendency the governor should be damped sufficiently so that it does not respond to these regular oscillations of the engine speed.

Owing to the friction of the mechanism, valves, etc., the governor of a steam engine will always have a certain amount of lag—*i.e.*, there must be a certain change in speed before the throttle valve operates. If ω_1' and ω_2' denote the greatest and least angular velocity which is possible without the governor acting, then the expression—

$$\varepsilon = \frac{\omega_1' - \omega_2^{2}}{\omega_m}$$

may be termed the coefficient of insensibility. In Fig. 1 there have also been plotted the values of ω_1' and ω_2' as a function of the load. Now since the angular speed during one revolution can vary within the limits $\pm \frac{1}{2} \delta \omega_m$ without the governor being affected, this amount must be subtracted from ω_1' and added to ω_2' so as to give the curves ω_1'' and ω_2'', which represent respectively the greatest mean velocity and the smallest mean velocity which the engine can have without the governor acting. With a given load on the machine the mean angular velocity of the set can therefore vary between narrow limits; that is, the governor possesses a certain amount of stability, shown by the shaded portions below and above the mean curve of Fig. 1. With steam or water turbines the cyclic irregularity would be zero, so that the curves ω'' and ω' would coincide.

When several identical and equally loaded alternators are connected to the same busbars and are driven by identical engines the load will not necessarily be equally shared between all the machines. For if

there be drawn in Fig. 2 a horizontal line corresponding to the mean angular velocity Ω_m of all the machines, it will, for a considerable distance, be inside the shaded part, and thus at this speed the machines can be loaded quite unequally. This difference of loading will be greater the flatter the speed curves are, *i.e.*, the smaller the drop of the governor. If the governors are of the isochronous or static type, the speed will remain constant independent of the position of the governor balls. The curves of Fig. 2 will therefore be horizontal lines, and the load between the various machines will remain as adjusted. Such governors are therefore quite unsuited for engines driving alternators in parallel.

With non-isochronous governors the load will be the more uniformly distributed between the various machines the less the difference between the two curves ω_1'' and ω_2''—that is, the more the value of δ and ϵ approach each. The governor must, however, be damped

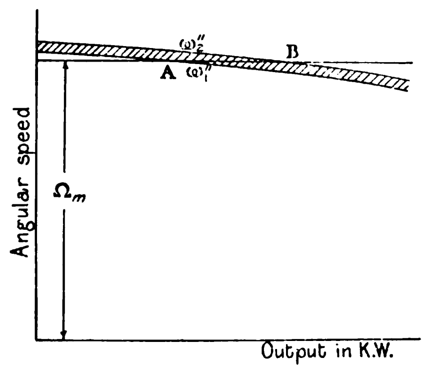


FIG. 2.

sufficiently so that ϵ is never less than δ, for otherwise the governor would operate every revolution and thereby cause hunting. Further, with a governor of given stability the steeper the speed curves the shorter will be the length A B, and the more uniformly will the load distribute itself between the various machines. On this account a large governor drop is an advantage in so far as parallel running is concerned; but a large drop also involves a large alteration in the frequency of the current between no load and full load. Hence the regulation of the governor should not be chosen greater than is actually necessary for good parallel working. Where the frequency must be the same for all loads it is necessary to alter the sensitiveness of the governor as the load varies, and this may be performed either by hand or automatically. For lighting plants hand regulation is quite sufficient, but for power plants where the load undergoes rapid fluctuations automatic regulation, which usually takes the form of an electric relay controlled from the switchboard, is essential.

In Fig. 3 the mean angular velocity Ω_m has been plotted as a function of the load for three identical engines, the governors of which have been adjusted to different positions in each case. The speed curves, though running almost parallel to each other, will, owing to the different setting of the governors, not coincide so that for a given angular speed Ω the mean loads W_1, W_2, and W_3 will be different. Hence it is possible to alter the loading of any machine by simply adjusting the setting of the governor.

Phase Displacement and Synchronising Current.—When the load on an alternator varies the speed of the prime mover changes, thus causing the governor to alter the amount of steam taken by the engine. Suppose the load to be decreased, then since a change of speed must occur before the governor acts, the excess of steam above that actually required for the new conditions of load will cause the engine to

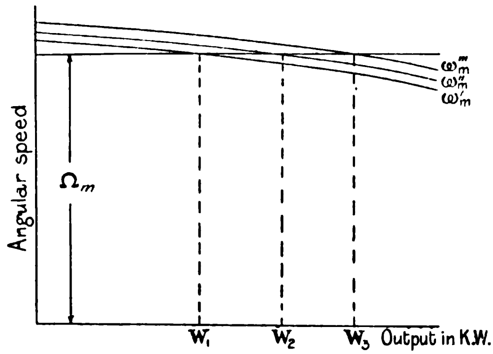


FIG. 3.

accelerate and exceed the synchronous speed, thus producing a difference in the relative phase positions of the considered alternator and the others connected to the busbars. Suppose that at any instant of time a, expressed in electrical degrees, denotes the angle by which the field system is ahead of the synchronous position, then for this instant the phase relation between the alternator and busbar pressure would be as in Fig. 4. The vectors O E_1 and O E_2' of equal magnitude represent respectively the phase relation of the busbar voltage and the terminal voltage of the considered machine when the rotor of the latter is revolving at a perfectly uniform speed corresponding to exact synchronism. On reducing the load any momentary acceleration of the rotor will cause the field system to overshoot the synchronous position, with the result that the vector O E_2 will then be ahead of the former position by an angle a. The voltages O E_1 and O E_2 will now have a resultant O E_r, which, since the armature resistance is small compared with the impedance, sets up a current O I_r almost in

quadrature with $O\,E_r$. Now, as $O\,I_s$ make an angle of nearly $\pm\frac{a}{2}$ to each of the voltage vectors $O\,E_1$ and $O\,E_2$, the current I_s is nearly a true watt current. If z_a denotes the impedance of the armature, then $O\,I_s = O\,E_r/z_a$. Since the component of $O\,I_s$ in phase with $O\,E_2$ acts in the same direction, the current I_s is generated with respect to E_2, and so causes the considered alternator to retard in phase.

Should the field system, due to an increase of load, fall slightly behind the synchronous speed, the vector $O\,E_2$ will now lag behind $O\,E_2'$ (see Fig. 5), thus causing the vector $O\,E_r$ of resultant E.M.F. to fall to the right-hand side of the ordinate reference axis. Since the current I_s set up by the resultant E.M.F. is in the opposite direction to $O\,E_2$, it is a motor current in respect to the alternator and so accelerates it. The circulating current I_s has therefore, for both positive and

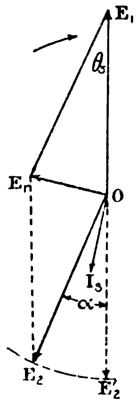


FIG. 4.

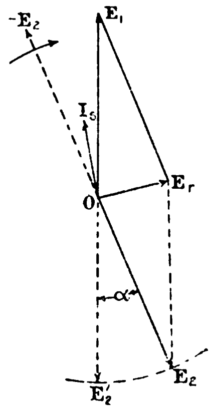


FIG. 5.

negative values of a, the effect of decreasing the divergence between the relative rotor position of the considered alternator and the others connected to the busbars, and, besides doing work in heating its own circuit, keeps the machine in synchronism by maintaining the correct phase position. I_s is therefore known as the "synchronising current," the magnitude of which varies periodically with the phase angle a.

In the case considered above it has been assumed that the machines represented by $O\,E_1$ have an infinitely greater power than the considered alternator. A second extreme case must, however, be taken into account, namely, where an alternator A_2 is working in parallel with another alternator A_1 of approximately the same output. Any phase displacement of A_2 relative to A_1 will give rise to a synchronising current $I_s = \frac{E_r}{2\,z_a}$, where z_a denotes the impedance of each machine. This current will affect machine A_2 in the same manner as described

above, but in addition A_1 will be oppositely affected. Thus, if the phase displacement of A_2 be positive, the synchronising current is a generator current in relation to A_2, but a motor current with regard to A_1. The latter machine is thus accelerated owing to the increased input, whilst A_2 is retarded.

Free Oscillations.—When, owing to a decrease in the resisting torque of the prime mover, an alternator accelerates, the mass of its rotating system will obtain an increased momentum, and this, as already stated, causes the field system to overshoot the synchronous position by a small angle a. The resulting synchronising current exerts a torque which pulls the system back. On its backward course the rotor gains sufficient momentum in the opposite direction to cause it to pass the correct position, whereupon the direction of the synchronising torque reverses, thus again causing the rotor to accelerate and pass the synchronous position. An oscillation about the synchronous position—*i.e.*, phase swinging—is thus set up, and this is accompanied by current surges between the alternator under consideration and the other machines connected to the busbars. These free oscillations when once started would, if no damping forces were present, continue indefinitely. The oscillation of power between the busbars and the alternator is, however, opposed by electrical and mechanical damping, which cause the oscillations to be of a gradually decreasing amplitude, until finally the alternator settles down to a steady state of running. Free oscillations similar to the above are also set up when an alternator is connected to the busbars slightly out of phase, but in general they will prove quite harmless, so long as they are not large enough to throw the alternator out of step in the first instance, and provided no other oscillations interfere with them.

Synchronising Power.—The synchronising current, which, as already explained, is in quadrature with the resultant voltage producing it, is expressed by—

$$I_s = E_r/z_a.$$

The impedance z_a will be given by the quotient of the voltage on open circuit and the short-circuit current for the same excitation, and for the sake of simplicity its value will be assumed as constant independent of the excitation and load. If the output of the alternator under consideration be small compared with those of all the other machines connected to the busbars, then the reactance of the other sets will be almost negligible in comparison. Now suppose that when the machines are running in parallel the excitation be taken off all the alternators except the one under consideration. This will mean a dead short-circuit, and the short-circuit current would approximate to that which would flow if the terminals of the excited alternator were shorted by a heavy cable. If I_0 denote the short-circuit current for the excitation that on open circuit generates the voltage $E = O\,E_2$ (Fig. 4), then—

$$z_a = E/I_0.$$

When this value of z_a is substituted in the above equation for I_s, the following expression is obtained for the synchronising current—

$$I_s = I_0 \cdot \frac{E_r}{E}.$$

Now from Fig. 4—

$$E_r = O\,E_r = 2 \cdot O\,E_2 \sin\frac{a}{2} = 2\,E \sin\frac{a}{2},$$

hence—

$$E_r/E = 2 \sin\frac{a}{2}$$

and—

$$I_s = I_0 \cdot 2 \sin\frac{a}{2}.$$

When two alternators, of the same size and therefore having approximately the same reactance, are worked in parallel, the conditions of short circuit are quite different. The removal of the excitation from one machine would mean a short circuit with single E.M.F. and double reactance, and therefore the current I_0 would just be one-half of that in the former case. To obtain full short-circuit current through both machines it would be necessary to parallel the two machines fully excited and 180° out of phase. Then the double E.M.F. shorted on the double reactance would generate the normal short-circuit current.

In the case of an alternator working in parallel with other machines of infinitely greater power, the synchronising watts per phase corresponding to the current I_s is, from Fig. 4—

$$W_s = E\,I_s \cos I_s O\,E_2 \cong E \cdot I_s \cos\frac{a}{2}$$

$$= E \cdot I_0 \cdot 2 \sin\frac{a}{2} \cdot \cos\frac{a}{2} = E \cdot I_0 \sin a.$$

Since all the phases of a polyphase machine would have an equal effect, the synchronising power of an m-phase alternator is—

$$W_s = m \cdot E \cdot I_0 \sin a.$$

Now for small values of the angle a, $\sin a \cong a$; hence the equation for synchronising power becomes—

$$W_s = m\,E\,I_0\,a \quad \ldots\ldots\ldots \quad (1)$$

Oscillations due to Synchronising Torque.—If $\omega_m = \frac{2\pi R}{60}$, denotes the mean value of the angular velocity and M_s the synchronising torque in kg.-metres, then the synchronising power is also given by—

$$M_s \times \frac{2\pi R}{60} \text{ kg.-metres per second,}$$

i.e.—

$$W_s = M_s \times \frac{2\pi R}{60} \times 9{\cdot}81 \cong M_s \cdot R \text{ watts.}$$

Substituting this value for W_s, there is then obtained the following expression for synchronising torque—

$$M_s = \frac{m . E . I_0}{R} . a \text{ kg.-metres,}$$

where R is the speed of the rotor in revs. per minute. Now for a given machine and full-load excitation, the factor $m\,E\,I_0/R$ is approximately constant and denotes the synchronising torque m_s per radian of electrical displacement—*i.e.*—

$$M_s = m_s\,a.$$

If θ denotes the angle of space displacement corresponding to the phase displacement a, then $\theta = p\,a$, and—

$$M_s = \frac{m_s}{p} . \theta = \frac{m\,E . I_0}{p\,R} . \theta = c\,\theta \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where p = number of pairs of poles.

Suppose that the load on the generator be slightly increased, then the rotor will momentarily lag behind the synchronous position and the torque opposing the rotation which normally is M_n will now be $M_n + M_s = M_n + c\,\theta$. If now the additional load $c\theta$ be removed there will be a balance of torque of that amount available for accelerating the generator, which accordingly will tend to come back to the true synchronous position. After a time it will arrive at this position to which corresponds the torque M_n, but will then be moving with a velocity greater than that corresponding to steady running. In consequence of the difference of velocity, the generator will not exert the steady motion torque M_n corresponding to the constant losses and the steady electrical load, but there will be a balance of torque tending to accelerate it or retard it, due to the speed being incorrect. For a small difference of angular velocity, the unbalanced torque will be proportional to the difference in velocity and $= k . \frac{d\,\theta}{d\,t}$, where k is a constant denoting the moment per unit angular velocity. Let $\Sigma\,m\,r^2$ denote the moment of inertia of the rotor, then since the moment of inertia of a rotating mass multiplied by its angular acceleration equals the moment of the forces about the axis, the general equation to the motion of the rotor will be—

$$\Sigma\,m\,r^2 \frac{d^2\,\theta}{d\,t^2} + k . \frac{d\,\theta}{d\,t} + c\,\theta = 0.$$

The solution of this differential equation is of the form—

$$\theta = \theta_0\,\epsilon^{-\frac{k}{2\,\Sigma\,m\,r^2} . t} \sin\,(T_0 t + \beta),$$

where θ_0 and β are constants depending on the initial conditions.

The importance, or otherwise, of the free oscillations depends almost entirely upon the sign of the constant k; that is, upon the way

in which they are damped. If k is positive, the oscillations are of a continually diminishing amplitude, and are finally damped out. On the other hand, if k be negative, even though very small, the amplitude of the oscillations will continually increase according to an exponential law, until the machine falls out of step. In actual machines, however, there are a number of causes which give rise to real viscous forces, and generally overcome this tendency to instability. Such are the local currents induced in the substance of the armature conductors, and the effects of currents induced by the oscillations in the pole-pieces, the field coils, and amortisseurs. The eddy currents induced in the iron and copper of an alternator are generally of such magnitude as to assign a positive value to k.

Periodic Time of a Free Oscillation.—The free oscillations of an alternator may be compared with those of a ring which is connected by means of a spiral spring to a fixed centre. If the ring be displaced by a momentary applied tangential force out of its position of equilibrium, the controlling force tends to bring it back to its central position. The ring is thus set vibrating, and if the magnitude of the controlling force varies in direct proportion to the displacement, the motion of any point on the ring will be a simple harmonic function of the time. Let $\Sigma m r^2$ denote the moment of inertia of the ring, then if m_m denote the restoring moment which would act if the ring were rotated from its position of equilibrium through unit angle, the time of a complete oscillation is expressed by—

$$T = 2\pi \sqrt{\frac{\Sigma m r^2}{m_m}}.$$

In the case of an alternator, the controlling moment of the spring is replaced by the synchronising torque and the ring by the rotating field system. Hence, if $\Sigma m r^2$ denote the moment of inertia of all the rotating parts, and m_r the synchronising torque per radian of mechanical displacement which acts at the instant the alternator deviates from the synchronous position, then the time of a free oscillation is—

$$T_1 = 2\pi \sqrt{\frac{\Sigma m r^2}{m_r}}.$$

It is, however, usual to express the periodic time in terms of the electrical displacement a; hence, since—

$$m_r = m_s p = \frac{M_s}{a} . p,$$

$$T_1 = 2\pi \sqrt{\frac{\Sigma m r^2}{\frac{M_s}{a} . p}} = 2\pi \sqrt{\frac{\Sigma m r^2}{\frac{p . 60}{2\pi R} . \frac{W_s}{a}}},$$

where—

$$\frac{W_s}{\omega} = \frac{W_s . 60}{2\pi R}$$

has been substituted for M_s. Now—

$$\frac{W_s}{a} = m\,E\,I_0,$$

and—

$$p = \frac{60 \sim}{R},$$

hence the periodic time of a free oscillation—

$$= T_1 = 0{\cdot}04\,R\sqrt{\frac{\Sigma\,m\,r^2}{m\,.\,E\,.\,I_0\,.\sim}} = 0{\cdot}04\,R\,.\sqrt{\frac{\Sigma\,m\,r^2}{m\,E\,I\,.\,\frac{I_0}{I}\,.\sim}}$$

$$= 0{\cdot}04\,R\sqrt{\frac{\Sigma\,m\,r^2}{\text{k.v.a.}\sim\cdot\frac{I_0}{I}}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

where I is the normal full-load current per phase and k.v.a. is the output of the alternator in kilovolt-amperes. The periodic time of a free oscillation therefore varies as the square root of the moment of inertia and inversely as the ratio of short-circuit current to normal full-load current. In order to obtain as steady running as possible, it is essential that the time of a swing be long. Hence, since T_1 varies inversely as the square root of $\frac{I_0}{I}$, it will be of advantage to design an alternator for a high reactance. Machines with inferior regulating properties are therefore better suited for parallel working than similar machines designed for very close regulation.

Where free oscillations are the only ones, no trouble will be experienced in parallel working of machines of normal design, and this is proved by the fact that turbo-alternators, owing to the uniform driving torque of the turbines, have given practically no trouble when operated in parallel. However, when the alternators are driven by reciprocating engines, the problem is more complicated.

Forced Oscillations.—The free oscillations which have just been discussed are those executed by the alternator when disturbed by a temporary change of conditions, *e.g.*, when switched into parallel with other machines before exact synchronism is obtained, or when the load on the machine is suddenly altered. These oscillations in themselves are not likely to cause instability of working, but should their periodic time be the same as, or approximate to, other oscillations impressed upon the alternator by the prime mover, steady motion will, unless the free oscillations are otherwise damped, be impossible and the phenomenon of hunting occurs.

Consider a single-crank double-acting steam engine, then on each inlet of steam there is produced a knock upon the piston, which will be transmitted to the field system so as to accelerate it. This occurs twice for every revolution, and the velocity curve of the rotor will

therefore be a series of waves (see Fig. 6) with two peaks per revolution. A two-crank engine, with the cranks at 90°, will show four velocity peaks per revolution, the peaks, however, being less pronounced. The "coefficient of speed variation" or "cyclic irregularity," as expressed by—

$$\delta = \frac{\text{max. vel.} - \text{min. vel.}}{\text{av. vel.}} = \frac{\omega_1 - \omega_2}{\omega_m} \quad . \quad . \quad . \quad . \quad . \quad (4)$$

is smaller the less the difference between the minimum and maximum velocities, and varies inversely as the moment of inertia of the rotating system.

The variations of speed produced by the irregular turning moment of a reciprocating engine may be considered as periodic oscillations

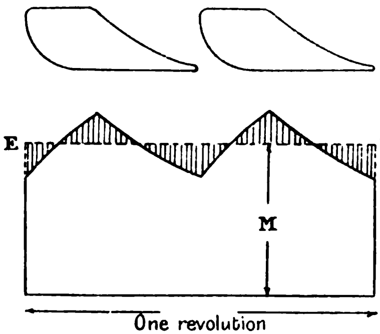


FIG. 6.

which are impressed upon the field system. The time of an oscillation for a single-crank double-acting engine is $T_2 = \frac{30}{R}$; for a two-crank engine with cranks at 90°, $T_2 = \frac{15}{R}$; and for a three-crank engine with cranks at 120°, $T_2 = \frac{10}{R}$, R denoting the speed in revs. per minute. If for any alternator the time of a forced oscillation is equal, or nearly equal, to the time of a free oscillation "resonance" will result, and the extent of the phase swinging will gradually increase and cause the alternator to fall out of step.

The relative crank positions of two sets supplying energy to the same network also influences the nature of the oscillations. Considering two similar sets in Figs. 7 and 8 there will evidently be greater turning moments than in Figs. 9 and 10; hence if two machines are paralleled when the crank of one is in a position as shown in Fig. 7 while that of the other engine is in a position represented by Fig. 9, the different angular velocities will produce

a phase displacement between the two alternators and phase swinging will result. Better conditions of working would obviously be obtained if the machines could be paralleled at an instant when electrical and mechanical synchronism coincided. This, however, makes the process of synchronising somewhat more complicated, for besides the phase lamps or meters, a couple of bells must be observed, the bell circuits being momentarily closed for a particular position of the crank. Owing to the complications involved, synchronism of the crank positions is only resorted to in the case of very slow speed machines, which are liable to give trouble through hunting.

In order to obtain a formula for the displacement resulting from uneven turning moment it is necessary to have the torque diagram of the prime mover. This is represented by a series of irregularly

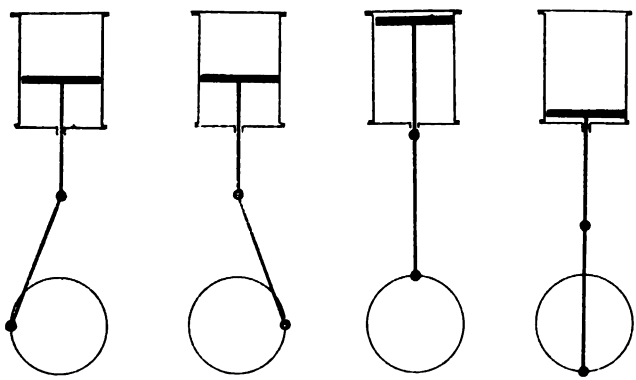


FIG. 7. FIG. 8. FIG. 9. FIG. 10.

formed waves (Figs. 6 and 11) repeating themselves at regular intervals, and for the purpose of calculation the diagram may be considered as made up of a constant torque M and a superimposed oscillating torque. The latter can, of course, be analysed into its fundamental and various harmonics, the fundamental period being taken as the time of one revolution. In well-balanced steam engines the fundamental wave, produced by inequality of the steam pressures on the two sides of a double-acting piston and imperfect static balance of the moving masses, will be small. The waves of greatest amplitude are :—

Single-crank engine	2nd harmonic.
Two-crank engine	4th „
Three-crank engine...	6th „

Besides these, harmonics of a higher order will exist, but they will in general not be of very great importance, and can be neglected.

In order to simplify matters it will be assumed that for a constant load the curve showing the elevation of crank effort from the mean

value can be replaced by an equivalent sine curve having the same periodic time as the harmonic of greatest importance. The error caused by substituting a sine curve in place of the irregular curves is quite small, comparable with the error that is likely to occur by assuming that the current curve of an alternator is a sine wave. Of course, in certain types of gas engines such an assumption would be far removed from actual facts, and in such cases the actual crank effort curve should be resolved into its various harmonics and those of most importance investigated separately. For example, in Fig. 11 there is given the turning moment diagram for a 1,000-B.H.P.

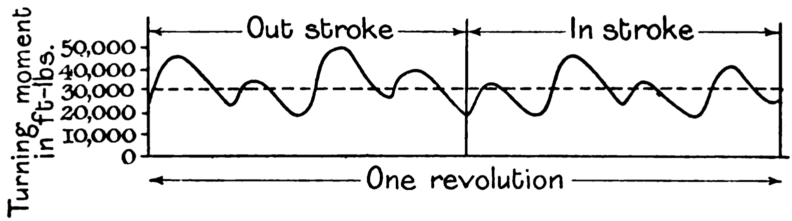


FIG. 11.

British Westinghouse gas engine of the vertical tandem type with four pairs of cylinders. When analysed into its harmonics the equation to the turning moment is—

$$m = 31000 + 1929\cos(\theta + 337^\circ) + 496\cos(2\theta + 119^\circ) + 6354\cos(3\theta + 289^\circ)$$
$$+ 354\cos(4\theta + 227) + 3378\cos(5\theta + 86^\circ).$$

If $m_{\text{max.}}$ denotes the amplitude value of the oscillating torque, then assuming the latter varies sinusoidally, the torque at any instant of time t—

$$= M + m_{\text{max.}} \sin \frac{2\pi t}{T_2}.$$

If $\Sigma m r^2$ denotes the moment of inertia of the rotating system, then the oscillating torque causes an oscillating acceleration expressed by—

$$\gamma = \frac{m_{\text{max.}}}{\Sigma m r^2} \cdot \sin \frac{2\pi t}{T_2} = \gamma_{\text{max.}} \sin \frac{2\pi t}{T_2},$$

where $m_{\text{max.}}/\Sigma m r^2$ denotes the amplitude value of the acceleration curve.

The oscillating torque will, of course, cause an oscillation of the magnet wheel around the synchronous position, but the angular displacement will be by no means in phase with the oscillating torque. As the acceleration varies according to a sine wave, the angular speed increases so long as the acceleration is positive (Fig. 12), and when the acceleration goes through the zero value the speed will be a maximum. When the acceleration is negative the speed decreases, and the mini-

mum value of the speed will be attained when the acceleration goes again through zero. That means that the oscillations of speed will lag by just a quarter of a period behind the oscillations of torque.

Let ω denote the instantaneous value of the angular speed and Ω the constant speed upon which the oscillating speed is superimposed, then—

$$\begin{aligned}
\omega &= \text{average speed} + \text{variable speed.} \\
&= \Omega + \int \gamma . d t = \Omega + \gamma_{\max} \int \sin \frac{2 \pi t}{T_2} . d t \\
&= \Omega + \gamma_{\max.} \frac{T_2}{2 \pi} . \cos \frac{2 \pi t}{T_2} \\
&= \Omega + \gamma_{\max.} \frac{T_2}{2 \pi} . \sin \left(\frac{2 \pi t}{T_2} - \frac{\pi}{2} \right) \\
&= \Omega + \omega_{\max.} \sin \left(\frac{2 \pi t}{T_2} - \frac{\pi}{2} \right),
\end{aligned}$$

where the amplitude value of the variable speed—

$$= \omega_{\max.} = \gamma_{\max.} \frac{T_2}{2 \pi}.$$

Now the coefficient of speed variation is expressed by—

$$\delta = \frac{\omega_1 - \omega_2}{\omega_m} = \frac{(\omega_m + \omega_{\max.}) - (\omega_m - \omega_{\max.})}{\omega_m} = \frac{2 \omega_{\max.}}{\omega_m}$$

i.e.—

$$\omega_{\max.} = \frac{\delta \omega_m}{2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

So long as the oscillating speed is positive the displacement will increase and attain its maximum value when the oscillating velocity passes through zero. Now the amplitude of the displacement is the integral of velocity and time, *i.e.*—

$$\begin{aligned}
\text{Displacement} = s &= \int \omega . d t = \omega_{\max.} \int \sin \left(\frac{2 \pi t}{T_2} - \frac{\pi}{2} \right) \cdot d t \\
&= \omega_{\max.} \frac{T_2}{2 \pi} . \sin \left(\frac{2 \pi t}{T_2} - \pi \right) = S_{\max.} . \sin \left(\frac{2 \pi t}{T_2} - \pi \right)
\end{aligned}$$

where $S_{\max.}$ has been substituted for—

$$\omega_{\max.} \cdot \frac{T_2}{2 \pi}$$

the oscillating displacement when superimposed upon the average position will lag 90° behind the oscillating speed, and 180° behind the oscillating torque or acceleration (see Fig. 12). If no other variable forces are acting upon the rotating field system, then the displacement is exactly inverse to the primary oscillating torque. At the instant when the accelerating force is greatest, the backward displacement will be a

maximum, and the machine at this instant supplies less than its normal power to the busbars.

Since—

$$\omega_{\max.} = \frac{\delta\,\omega_m}{2},$$

the maximum displacement can be expressed thus :—

$$S_{\max.} = \omega_{\max.} \cdot \frac{T_2}{2\,\pi} = \frac{\delta\,\omega_m}{2} \cdot \frac{T_2}{2\,\pi} = \frac{\delta}{4\,\pi} \cdot \omega_m\,T_2.$$

Now T_2 is the time of one cycle, hence $\omega_m T_2$ is the distance traversed

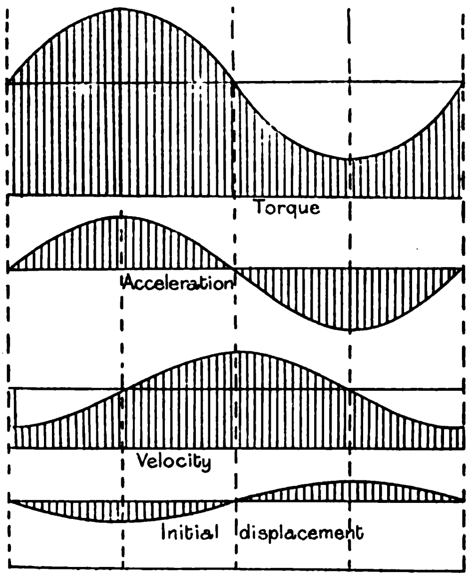


FIG. 12.

per cycle. Further, if n_c denote the number of impulses per revolution the distance traversed per cycle—

$$= \omega_m\,T_2 = \frac{2\,\pi}{n_c},$$

and—

$$S_{\max.} = \frac{\delta}{4\,\pi} \cdot \frac{2\,\pi}{n_c} = \frac{\delta}{2\,n_c} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

Since p denotes the number of pairs of poles, the displacement expressed in electrical degrees is—

$$a_1 = \frac{\delta}{2\,n_c} \cdot \frac{360}{2\,\pi} \cdot p \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

From this equation it will be seen that the maximum phase displacement of the rotor due to the uneven turning moment of the prime mover is directly proportional to the coefficient of speed variation and inversely proportional to the number of cycles per revolution.

On page 291 it was shown that—

$$S_{max.} = \omega_{max.} \cdot \frac{T_2}{2\pi};$$

but—

$$\omega_{max.} = \gamma_{max.} \cdot \frac{T_2}{2\pi},$$

and—

$$\gamma_{max.} = \frac{m_{max.}}{\Sigma m r^2}.$$

Hence—

$$\left.\begin{aligned} S_{max.} &= \frac{m_{max.}}{\Sigma m r^2} \cdot \frac{T_2^2}{4\pi^2} \text{ mechanical radians} \\ &= \frac{m_{max.}}{\Sigma m r^2} \cdot \frac{T_2^2}{4\pi^2} \cdot p \text{ electrical radians} \end{aligned}\right\} \quad \ldots\ldots \quad (8)$$

If $K_g D^2$ denote the flywheel effect in kg.-metres², where K_g denotes the weight of rotating masses in kilogrammes and D is the diameter of gyration in metres, then—

$$\Sigma m r^2 = \frac{K_g D^2}{4 \cdot g},$$

where g, the acceleration due to gravity, $= 98{\cdot}1$ in kilogramme and metre units.

Effect of Synchronising Torque upon Displacement resulting from Forced Oscillation.—So far it has been assumed that the resisting torque is that due to the load only, and is therefore constant. But when the rotor of an alternator working in parallel with others deviates from the synchronous position a torque is set up tending to pull the field system back to the mean position. The synchronising torque will vary in phase with the displacement, being alternately positive or negative according as the machine leads or lags; hence if there is no damping the oscillations in the synchronising torque will lag 180° behind the oscillations in the driving torque. When the synchronising torque corresponding to any oscillating displacement of amplitude a_1 is superimposed upon the oscillating torque due to the prime mover, the result is that the amplitude of the oscillating torque is augmented, thus increasing the acceleration, the variable velocity, and the displacement beyond the original values. This will in turn give a larger synchronising torque and correspondingly increased displacement, the cycle of operations being repeated until a final displacement a_0 is reached. The diagrams in Fig. 12 are therefore not quite correct, and should be rectified step by step by aid of the combined diagram Fig. 12A until the ultimate displacement a_0 is obtained. The determination of the synchronising torque in this manner would be very laborious. The

following graphical construction due to E. Rosenberg,* forms, however, a basis for a more rapid solution of the problem

Referring to the vector diagram of Fig. 13, let O A represent the amplitude value of the oscillating torque as obtained from the diagram of crank effort. This vector will be supposed to make one revolution in the time T_2 (= time of one cycle), its projection on the horizontal axis giving the instantaneous value of the variable torque. The second vector O B, lagging 90° with regard to O A, represents the amplitude of the oscillating speed. Now since the oscillating displacement lags 90° behind the oscillating speed, and 180° behind the initial oscillating torque, its amplitude value can be represented by the vector O C. Each vector must, of course, be drawn to its proper scale, so that there are actually three scales, but each bearing a definite ratio to the preceding one. The scale for O C should, further, be such that O C in the scale of the driving torque represents the synchronising torque due to the displacement a_1.

With an original displacement O C, then, owing to the reaction of the prime mover, the actual vector of variable torque is not O A, but O A + O C. The increased oscillating torque produces, of course, an

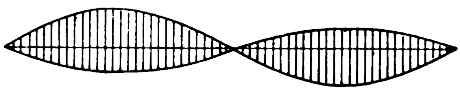


FIG. 12A.—Combined Diagram.

increased displacement, which goes on until the final displacement a_0 is attained. The latter is found as follows : Draw O B_1 parallel to A B, C B_1 parallel to O B, and $B_1 C_1$ parallel to B C ; then, since $\frac{C C_1}{O C} = \frac{O C}{O A}$, C C_1 will represent the additional displacement. Repeating this construction, it will be found that the points B, B_1, B_2, etc., lie on a straight line, so that the final lead O C_0 will be found by going through the construction once and producing the line B B_1 until it cuts the vertical axis in C_0. The final value of the oscillating torque is then represented by $C_0 A = O A + O C_0$, and if from C_0 a line be drawn parallel to C B it will cut off from the horizontal the length O B_0 which represents the final value of the oscillating speed. Since the triangles C B_1 O and O B A are similar—

$$\frac{C B_1}{O B} = \frac{O C}{O A} = \frac{\text{synchronising torque}}{\text{variable torque}} = q = \text{reaction quotient},$$

i.e.—

$$C B_1 = q \,.\, O B, \quad \text{or} \quad O C = q \,.\, O A;$$

also—

$$\frac{O C_0}{O C} = \frac{O B}{O B - O D} = \frac{O B}{O B - C B_1} = \frac{O B}{O B - q O B} = \frac{1}{1 - q}.$$

* *Proceedings of the Institution of Electrical Engineers*, vol. 42, p. 533, 1909.

Hence the final value of the synchronising torque is expressed by—

$$O\,C_0 = \frac{1}{1-q}\,.\,O\,C = \frac{q}{1-q}\,.\,O\,A.$$

The factor $\frac{1}{1-q}$, called by Rosenberg the multiplying factor, is a very important characteristic to be taken into account when an alternator has to be operated in parallel with other machines. For, with a given oscillating torque, the final displacement a_0 will depend upon the value $\frac{1}{1-q}$. Thus if the synchronising torque equals $\frac{1}{10}$, $\frac{1}{5}$, or $\frac{1}{4}$ of the initial variable torque, the final displacement will be $\frac{10}{9}$, $\frac{5}{4}$, or $\frac{4}{3}$ times

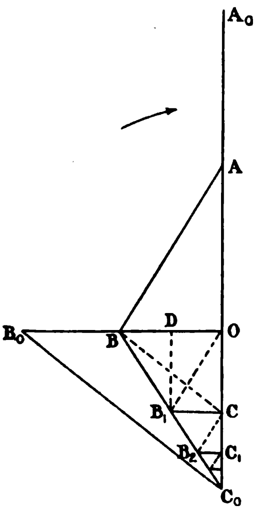


FIG. 13.

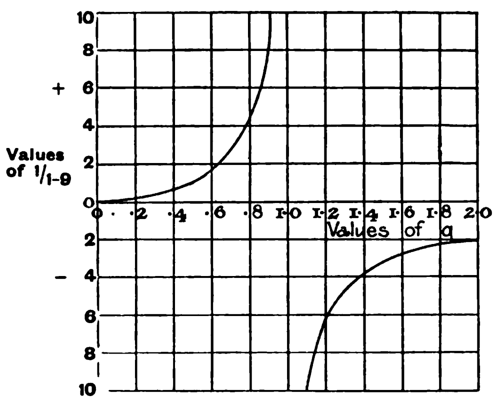


FIG. 14.

the initial displacement, while the actual coefficient of speed variation is $\frac{10}{9}$, $\frac{5}{4}$, or $\frac{4}{3}$ times greater than that due to the prime mover alone.

Since the scale O C also represents the angular displacement of the rotor, it follows that for an initial displacement a_1 the final value will be expressed by—

$$a_0 = \frac{1}{1-q}\,.\,a_1 \quad \ldots\ldots\ldots\ldots \quad (9)$$

When q is less than unity the factor $\frac{1}{1-q}$ will have finite values; but if $q = 1$ its value will be infinite. That means that for any initial oscillating torque, except for one of infinitesimal value, the final oscillations would be infinite when $q = 1$. This state of affairs is reached if the duration of an oscillating torque cycle is exactly equal to the

periodic time of a free oscillation—*i.e.*, when there is complete resonance. If q be greater than 1, the factor $\frac{1}{1-q}$ will again be finite, but with the sign changed. In Fig. 14 the values of $\frac{1}{1-q}$ have been plotted as a function of q, and it will be noted that near the point of resonance—*i.e.*, when $q \cong 1$, the displacement increases very rapidly. It is therefore not advisable to approach too closely the critical value of q, for oscillations when once started by any small amount of speed variation may rapidly increase to such an extent that parallel running is impossible and the alternator drops out of step. Although it is always desirable to keep the initial displacement small, the stable running of alternators in parallel does not depend so much upon this as upon the value of the reaction quotient q. This should be kept as small as possible in order to keep down the final displacement and the resulting surging of power between the machine and the busbars.

Damping.—In actual machines the above-mentioned points of instability where the value of the factor $\frac{q}{1-q}$ changes from $+\infty$ to $-\infty$, does not really exist because the free oscillations are to a more or less extent damped by the presence of a third torque. When the armature of a polyphase alternator supplies current, a rotating magnetic field is set up by the armature M.M.F., and should the magnet wheel not be in perfect synchronism with this field, but show an oscillation superimposed upon the synchronous motion, currents will be induced in every closed circuit that presents itself on or near the pole-face. The currents are proportional to the vector of oscillating speed and set up a torque directly opposed to it—*i.e.*, they tend to damp the oscillations. When amortisseur coils are fitted into the pole-shoes the induced currents, and hence the torque corresponding to a given oscillating speed, will be high. Should there only be solid pole-shoes, the higher resistance of the iron will then reduce the damping torque for a given oscillating speed. With laminated pole-shoes the torque will be still further diminished, but as the laminations do not permit of large damping currents, the action will go deeper and will be visible in the field coils. Even with laminated pole-shoes a damping torque is always present which must be taken into account in the determination of the final displacement of the rotor.

The vector diagram of Fig. 13 must now be modified so as to take into account the torque due to damping. This latter can be determined experimentally by running the machine as an induction motor and loading on a suitable brake. The slip corresponding to any particular load is measured, and the ratio of brake torque to slip will be the same as the ratio between damping torque and oscillating speed, *i.e.*—

$$\text{Damping torque} = \text{oscillating speed} \times \frac{\text{brake torque}}{\text{slip}}.$$

The vector O D (Fig. 15), representing the damping torque is then drawn in opposition to the vector of variable velocity O B, the scale for the oscillating speed being so chosen that the length of the speed vector is identical with the length of the vector representing the damping torque corresponding to this speed. The primary oscillating torque, since it must have a component O D, equal and opposite to the damping torque, will no longer be exactly opposite in phase to the synchronising torque O C_o', but will lead by an angle of less than 180° as indicated by O A. The component of the torque which is effective in producing an initial displacement is therefore less than O A, and is represented by O A_1 = O A cos a_2, where a_2, the angle of damping, is expressed by—

$$a_2 = \sin^{-1} \frac{\text{damping torque}}{\text{initial oscillating torque}}.$$

The damping torque has therefore the effect of decreasing the initial displacement, but unless it has a value nearly equal to the primary oscillating torque, the action of the amortisseurs will have very little effect in diminishing the mechanical oscillations. For example, when the damping torque equals 50 per cent. of the primary torque O A, the effective component O A_1 is only reduced to 0·866 O A. In order that O A_1 may be one-half of the primary oscillating torque, the damping torque must be 87 per cent. of the primary torque O A.

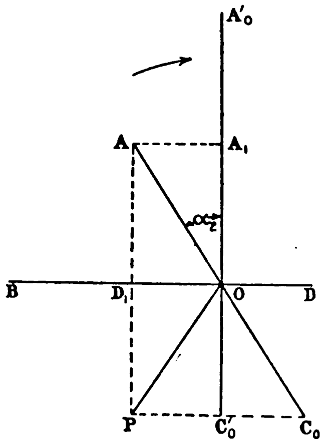


FIG. 15.

In a damped machine the oscillations in output are due not only to the synchronous oscillating torque O C_o', but also to the damping torque which is maintained by currents taken from, or supplied to, the network. Hence the oscillating power superimposed upon the average output of the machine consists of a synchronous component O C_o' in phase with and in the same direction as the displacement, and an asynchronous component O D_1 in phase with and in the same direction as the oscillating speed. The resultant of O D_1 and O C_o'—*i.e.*, O P—will then represent the oscillating torque from which arise the oscillations of power between the machine and the network.

Besides showing the effect of damping upon the mechanical oscillations, the diagrams in the last two figures also provide a means whereby the oscillations of power in a damped machine can be compared with the oscillations in a machine having negligible damping. Since the damping torque = O D_1 = O A sin a_2, and

$O C_0' = O C_0 \cos \alpha_2$ the oscillating torque transmitting power to the network is—

$$O P = \sqrt{(O C_0')^2 + O D_1^2} = \sqrt{O C_0^2 \cos^2 \alpha_2 + O A^2 \sin^2 \alpha_2}.$$

From Fig. 15 it is obvious that when $O C_0 = O A$, $O P = O C_0$, and that $O P$ will be greater or less than $O C_0$ according as $O A$ is greater or less than $O C_0$. From this it follows that when $O P = O C_0$—

$$\frac{q}{q-1} = \frac{O C_0}{O A} = \frac{O C_0}{O C_0} = 1$$

$$(i.e., q = 0{\cdot}5) ;$$

but when $O P$ is greater or smaller than $O C_0$, $\frac{q}{1-q}$ is smaller or greater than 1. Though damping in all cases decreases the mechanical oscillations, the power oscillations decrease only when $\frac{q}{1-q}$ is more than 1. When $\frac{q}{1-q} = 1$ the power oscillations are unaffected by the damping torque. For values of $\frac{q}{1-q}$ less than 1 the damping actually increases the oscillation of power ; but this should give no trouble provided the fluctuations do not exceed about 25 per cent. of the normal output.

Example.—A certain 3-phase 50-∿ 3,300-volt alternator designed for a current of 180 amperes per phase at 0·9 power factor (*i.e.*, 900 k.w. or 1,000 k.v.a.) was direct coupled to a two-crank reciprocating engine running at 94 revs. per minute. The short-circuit current at full-load excitation was 550 amperes and the flywheel effect of the set was 600 ton-metres² (= 6×10^5 kg.-metres²). Each of the 64 field-poles was fitted with amortisseur windings, which at 1 per cent. slip developed a torque = 22 per cent. of the full-load torque. On analysing the torque diagram of the engine it was found that the 2nd harmonic was the only one of any importance, and this had an amplitude value equal to 7 per cent. of the normal full-load torque. From these data the oscillating output can be calculated as follows :—

$$\text{Full-load torque} = \frac{\text{watts output}}{9{\cdot}81} \cdot \frac{60}{2 \pi R} = \frac{9 \times 10^5}{9{\cdot}81} \cdot \frac{60}{2 \pi . 94}$$
$$= 9300 \text{ kg.-metres}^2.$$

$$\text{Amplitude value of oscillating torque} = M_{max.} = 0{\cdot}07 \times 9300$$
$$= 650 \text{ kg.-metres}^2.$$

$$\text{Periodic time of an impulse} = T_2 = \frac{60}{94{\cdot}2} = 0{\cdot}32 \text{ second.}$$

$$\text{Flywheel effect of the set} = K_g D^2 = 6 \times 10^5 \text{ kg.-metres}^2.$$

$$\text{Hence moment of inertia} = \Sigma\, m\, r^2 = \frac{K_g\, D^2}{4 \cdot g} = \frac{6 \times 10^5}{4 \times 98{\cdot}1} = 1520.$$

$$\text{Maximum displacement} = \frac{m_{\max.}}{\Sigma\, m\, r^2} \cdot \frac{T_2^2}{4\,\pi^2} \cdot 32 = \frac{650}{1520} \cdot \frac{0{\cdot}32^2}{4\,\pi^2} \cdot 32$$
$$= 0{\cdot}036 \text{ electrical radians,}$$

i.e.—

$$a = 0{\cdot}036.$$

The synchronising power due to this displacement—

$$= W_s = m \,.\, E \,.\, I_0\, a = \frac{3 \cdot 3300 \,.\, 550 \,.\, 0{\cdot}036}{1000} = 195 \text{ k.v.a.}$$

$$= 19{\cdot}5 \text{ per cent. of full-load output} = O\,C_0.$$

$$\text{Maximum displacement in electrical degrees} = 0{\cdot}036 \times \frac{180}{\pi} = 2{\cdot}05^\circ.$$

Since—

$$\text{Displacement} = \text{oscillating speed} \times \frac{T_2}{2\,\pi},$$

the oscillating speed—

$$= \frac{2\,\pi \times 2{\cdot}05}{0{\cdot}32} = 40 \text{ electrical degrees per second.}$$

Now 50 $\sim$ is equivalent to $360 \times 50 = 18000$ electrical degrees per second. Hence—

$$\text{Oscillating speed} = \frac{40}{18000} \times 100 = \pm 0{\cdot}22 \text{ per cent.}$$

$$\text{Damping torque} = \text{oscillating speed} \times \frac{\text{brake torque}}{\text{slip}}$$

$$= 0{\cdot}22 \times \frac{22}{1} = 4{\cdot}8 \text{ per cent. full-load torque.}$$

Initial oscillating torque $= 7$ per cent. full-load torque $= O\,A$; hence angle of damping—

$$= \sin^{-1} \frac{4{\cdot}8}{7{\cdot}0} = \sin^{-1} 0{\cdot}69 = 44^\circ = a_2.$$

$$\text{Oscillating output} = \sqrt{O\,C^2_0 \cos^2 a_2 + O\,A^2 \sin^2 a_2}$$
$$= \sqrt{19{\cdot}5^2 \,.\, 0{\cdot}71^2 + 7^2 \,.\, 0{\cdot}69^2}$$
$$= 25 \text{ per cent. of normal output.}$$

This value is, if anything, on the high side for stable working. By increasing the damping action to 6·3 per cent. full-load torque the oscillating output will be reduced to 11·8 per cent. of the normal full-load output. The corresponding angle of damping will be 65°.

Critical Periodic Time of an Oscillation.—The synchronising power of an m-phase machine is—

$$W_s = m \,.\, E \,.\, I_0 \,.\, a \text{ watts.}$$

Now, from equation (8)—

$$a = S_{max.} = \frac{m_{max.}}{\Sigma\, m\, r^2} \cdot \frac{T_2^2}{4\,\pi^2} \cdot p\,;$$

hence—

$$W_s = m \,.\, E \,.\, I_0 \,.\, \frac{m_{max.}}{\Sigma\, m\, r^2} \cdot \frac{T_2^2}{4\,\pi^2} \,.\, p.$$

Let T_r denote the time of a revolution, g the acceleration of gravity, and M_s the synchronising torque, then—

$$W_s = M_s \,.\, g \,.\, \frac{2\,\pi}{T_r},$$

or—

$$M_s = \frac{W_s}{g} \cdot \frac{T_r}{2\,\pi} = \frac{m\,E \,.\, I_0}{g} \cdot \frac{m_{max.}}{\Sigma\, m\, r^2} \cdot \frac{T_r\, T_2^2}{8\,\pi^3} \,.\, p.$$

Since the reaction quotient is the ratio of synchronising torque to initial oscillating torque—

$$q = \frac{M_s}{m_{max.}} = \frac{m\,E \,.\, I_0}{g} \cdot \frac{1}{\Sigma\, m\, r^2} \cdot \frac{T_r \,.\, T_2^2}{8\,\pi^3} \,.\, p.$$

If for $\Sigma\, m\, r^2$, T_r, and p the following substitutions be made—

$$\Sigma\, m\, r^2 = K_g\, D^2/4\,g$$

$$T_r = 60/R$$

$$p = \frac{60 \sim}{R}$$

$$q = \frac{m\,E \,.\, I}{g} \cdot \frac{I_0}{I} \cdot \frac{4\,g}{K_g\, D^2} \cdot \frac{60\, T_2^2}{R\, 8\,\pi^3} \cdot \frac{60 \sim}{R}$$

$$= 5{\cdot}8 \times 10^4 \frac{\text{k.v.a.}\, T_2^2 \sim}{K_g\, D^2 \,.\, R^2} \cdot \frac{I_0}{I} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

Now when $q = 1$, the synchronous torque is equal to the initial oscillating torque and the oscillations will increase indefinitely. For such a condition the critical periodic time of an oscillation is—

$$T_{crit.} = 4{\cdot}2 \times 10^{-3}\, R \sqrt{\frac{K_g \,.\, D^2}{\text{k.v.a.} \sim \,.\, \frac{I_0}{I}}} \quad . \quad . \quad . \quad . \quad . \quad (11)$$

Experience shows that the periodic time $T_2 \left(= \frac{30}{R\, n_c}\right)$ of a forced oscillation should not approach too closely the critical value, and the general practice is to make $T_{crit.}$ at least $1{\cdot}4\, T_2$; that is, the natural frequency of the alternator should not exceed 70 per cent. of the frequency of the impulses impressed by the prime mover.

Example.—In a certain station a number of 3-phase alternators, each

driven at 94 revs. per minute by a two-cylinder engine with cranks set at 90°, have to work in parallel. From the following data relating to the alternator the size of flywheel required for electrical purposes can be determined.

Output at normal full load ... ... = 1,000 k.v.a.
Short-circuit current ÷ full-load current = 3·1
Frequency ... ... = 50 ∿

$$\text{Periodic time of a forced oscillation} = \frac{30}{90 \times 2} = 0{\cdot}66 \text{ second.}$$

$$\text{Making } T_{crit.} = 1{\cdot}4\, T_2 = 1{\cdot}4 \times 0{\cdot}66 = 0{\cdot}92 \text{ second.}$$

$$0{\cdot}92 = 4{\cdot}2 \times 10^{-3}\, 94 \sqrt{\frac{K_g D^2}{1000 \,.\, 50 \,.\, 3{\cdot}1}}.$$

Hence flywheel effect necessary—

$$= K_g D^2 = \frac{0{\cdot}92^2 \,.\, 1{,}000 \,.\, 50 \,.\, 3{\cdot}1}{4{\cdot}2^2 \times 10^{-6} \,.\, 94^2}$$
$$= 8{\cdot}3 \times 10^5 \text{ kg.-metres}^2 = 830 \text{ ton-metres}^2.$$

If these figures be adhered to, then dampers are quite unnecessary, but when the flywheel effect, which may be sufficient so far as the mechanical design and cyclic irregularity is concerned, is such as to give nearly the critical value for parallel working, then the use of dampers may save tons of flywheel. In general, it may be said that dampers should always be used when $T_{crit.}$ is less than $1{\cdot}4\ T_2$.

In practice a number of machines of different types and speeds may have to run in parallel—*e.g.*, turbo-alternators have to operate in parallel with other alternators driven by reciprocating engines. In such cases it is not only necessary to avoid equality between the natural frequency of the machine in question and the impulses due to its own prime mover, but also with the impulses from the engines driving the other sets. However, the prevailing type of steam engine in this country runs at such a high speed that most of the difficulties of parallel working are avoided, but in the case of alternators driven by gas engines or slow-speed steam engines the possibility of trouble from resonance should be carefully investigated.

Example.—A 2,000-k.v.a. 50-∿ 4-pole turbo-alternator, running at 1,500 revs. per minute, was installed in a station where there were already working two 1,000-k.v.a. slow-speed alternators direct coupled to a three-crank reciprocating engine running at 94 revs. per minute. When the turbo-alternator, which had a flywheel effect of 1,700 kg.-metres² and a short-circuit current equal to 2·1 normal full-load current, was operated in parallel with either or both of the two other sets, serious hunting occurred.

The periodic time of a forced oscillation due to impulse of reciprocating engine—

$$= T_2 = \frac{30}{94 \times 3} = 0{\cdot}106 \text{ second.}$$

Critical periodic time of turbo-alternator—

$$= T_{\text{crit.}} = 4 \cdot 2 \times 10^{-3} . 94 \sqrt{\frac{1800}{2000 \times 50 \times 2 \cdot 1}}$$
$$= 0 \cdot 114.$$

The periodic times of the forced oscillations were thus nearly equal to the critical value, and this explains why hunting troubles arose. The hunting was cured by fitting heavy dampers on the pole-shoes of the turbo-alternator, which was of the definite pole type.

Permissible Values of Phase Displacement and Cyclic Irregularity.—For the successful working of alternators in parallel the initial displacement a_1 of the field system from the synchronous position due to cyclic irregularity of the engine must be kept within certain limits, determined by the nature of the load upon which the machines are working. Since the initial displacement is given by—

$$a_1 = \frac{\delta}{2 n_c} . \frac{360}{2\pi} . p \text{ electrical degrees,}$$

$$\delta = 0 \cdot 035 . a_1 . n_c . \frac{1}{p}.$$

Hence, so far as parallel working is concerned, the permissible cyclic irregularity should, for a given phase displacement a_1, be directly proportional to the number of cranks and inversely proportional to the number of poles. Now, experience shows that to ensure stable conditions of working the maximum permissible initial displacement should be limited to ± 3 electrical degrees,* *i.e.*, $\pm 3/p$ space degrees. For instance, in the case of a three-crank engine direct coupled to a 50-∿ alternator running at 250 revs. per minute, $p = 12$, and the permissible cyclic irregularity should not exceed—

$$\sigma = 0 \cdot 0235 \times 3 \times 3 \times \tfrac{1}{12} = 0 \cdot 026 = \tfrac{1}{40}.$$

If the same type of engine were employed to drive an alternator of the same frequency at, say, 100 revs. per minute, then $p = 30$ and σ must be limited to $\frac{1}{110}$. Again, if similar engines were used for driving 25-∿ generators, the permissible cyclic irregularity could, for the same initial displaced, be as high as $\frac{1}{20}$ and $\frac{1}{60}$ respectively. These figures show that, in so far as parallel running is concerned, a low frequency is an advantage, for a larger coefficient of speed variation will be permissible, thus rendering it possible to work with a smaller flywheel mass.

In settling the limit of cyclic irregularity it should further be remembered that the driving torque of the prime mover is subject to continual changes, which are due to variations in the steam pressures,

* Engineering Standards Committee Report on Reciprocating Steam Engines for Electrical Purposes, 1909 (p. 6),

changes in the composition of the gas, varying loads, etc. The fluctuations in energy due to these changes may be greater than those of the normal diagram, but they are not in any way connected with the cyclic irregularity. A gas engine, or a single-crank steam engine with a large cyclic irregularity will take scarcely any notice of the fluctuations, as the flywheel effect will be sufficient to store the excess energy without the least trouble. But in a multi-crank steam engine set with a high degree of uniformity, the mean driving torque will differ comparatively little from the maximum. The flywheel mass, if settled solely from the permissible value of cyclic irregularity, would then be comparatively small, with the result that the above-mentioned irregular changes would, besides interfering with the free and the forced oscillations of the alternator, put severe strains upon the engine.

For these reasons the engine builders invariably give sufficient flywheel mass to limit the cyclic irregularity to about $\frac{1}{100}$ in the case of single-crank engines. In multi-crank sets a much smaller cyclic irregularity is desirable for purely mechanical reasons, so that the speed variations will seldom be less than $\frac{1}{150}$, whilst $\frac{1}{300}$ should be considered the limit in the other direction, as otherwise the cost of flywheel becomes too expensive.

Size of Flywheel.—In order to determine the size of flywheel required for a certain cyclic irregularity δ, there must first be obtained, from the combined indicator diagrams of the various cylinders, a crank-effort curve such as is shown in Figs. 6 and 11. If a mean-effort line be drawn, then the largest of the areas lying above or below the mean-effort line E F is called the fluctuation of energy δ E. The ratio of this to the total work done per cycle is called the coefficient of fluctuation of energy and will be denoted by κ. The value of κ will be considerably influenced by the number of cylinders and arrangement of the cranks, but for a given engine is constant. Knowing the value of κ the moment of inertia of the flywheel is then given by—

$$\Sigma m r^2 = \frac{\kappa \,.\, W'}{\delta \,.\, \omega_m{}^2}.$$

i.e.—

$$\text{Flywheel effect} = K_g D^2 = \frac{\Sigma m r^2}{4g} = \frac{\kappa W'}{4 \delta \omega_m{}^2 . g} \quad . \quad . \quad . \quad (12)$$

W′ denotes the work done per cycle and—

$$= 76 \text{ H.P. } T_2 \text{ kg.-metres.}$$

When, as will usually be the case in practice, the flywheel is designed by the engine builders for a good standard cyclic irregularity, the electrical engineer has only to check whether the given value is likely to cause trouble or not. In medium-speed sets the size of flywheel necessary for mechanical reasons will generally be ample to

keep the critical periodic time well above the limit mentioned above. In a slow-speed engine with a fixed flywheel effect, the critical value can be avoided by increasing the radial depth of air-gap so as to decrease the apparent impedance of the armature, and therefore to increase the value of the short-circuit current I_0. Such a procedure may, however, seriously endanger the regulating properties of the alternator, and in general cannot be applied to any great extent. In machines where the critical value is likely to be approached, the most satisfactory commercial result is obtained by a compromise between a large flywheel and a small short-circuit current. Of course, when near to resonance, dampers should always be fitted into the pole-shoes, and provided the primary oscillations are kept small, these may be sufficient to prevent hunting, even though complete resonance should nearly occur.

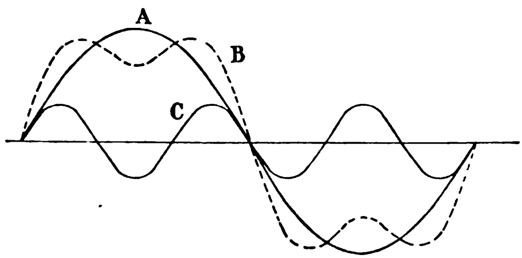


FIG. 16.

Influence of Shape of E.M.F. Waves.—So far it has been assumed that the E.M.F. waves, for all the alternators connected to the same network, are of the same shape, but when, as will often be the case, the forms of the E.M.F. curves are dissimilar, there will always be a resultant E.M.F. acting round the circuits between the various armatures.

For instance, consider the single-phase alternators whose respective E.M.F. waves, shown by A and B in Fig. 16, can be expressed by the equations—

$$E_A = E_1 \sin pt.$$

and—

$$E_B = E_1 \sin pt + E_3 \sin 3\, pt.$$

When these machines are worked in parallel the resulting E.M.F. acting through the circuits of the two armatures will be—

$$E_R = E_B - E_A = E_3 \sin 3\, pt.$$

This resultant E.M.F., represented by curve C, will set up a synchronising current having a frequency three times that of the

main current. Should the wave-forms be very dissimilar the resulting oscillations of current between the machine and the busbars might be so great as to reinforce the free oscillations of the machines and so produce hunting, and thus render parallel working impossible.

Alternators intended for parallel running should always be designed to give an E.M.F. wave which approximates very closely to a sine curve. For although the oscillations of power from this cause may not be large enough to cause unstable working, they increase the copper loss in the armature, and, further, should the periodic time of the forced oscillations approach too closely the natural period of the machine, the interference due to dissimilar wave-shapes may tend to produce resonance when large fluctuations in the load take place.

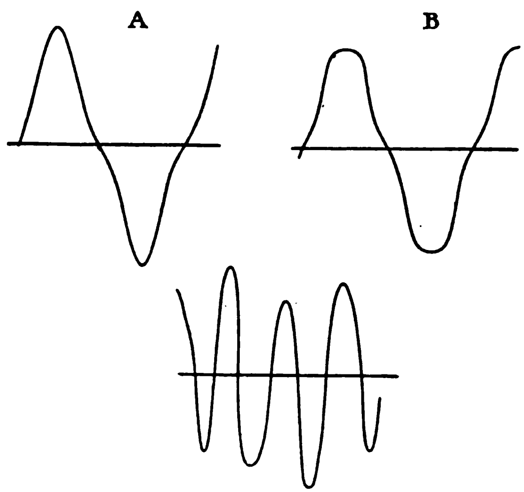


FIG. 17.

That the synchronising current due to this cause may, under certain conditions, be by no means a negligible factor will be obvious from the curves shown in Fig. 17. A and B are the open circuit E.M.F. curves for two 600-k.v.a. 2,000-volt single-phase alternators which are connected to the same busbars. The triple-frequency curve C is that of the synchronising current passing between the two machines when operated in parallel on a steady load and with their fields normally excited. The R.M.S. value of the synchronising current is in this case about 15 amperes.

Three-phase Alternators with Earthed Neutrals.—In order to prevent undue rise of potential in a 3-phase transmission system supplied with current from star-connected generators, the practice of earthing

the neutral-point of each winding is sometimes adopted. If, with earthed neutrals, the phase E.M.F. wave-form of the various machines differ from each other, then the resultant E.M.F. will set up local currents through the earth wire between the various generators as shown in Fig. 18. From the latter it will be observed that between

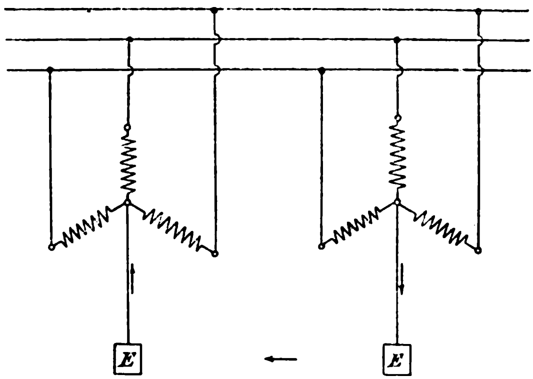


FIG. 18.

any two machines there are three circuits in parallel, with one earth return. The resultant E.M.F. due to the fundamental waves tending to send current through this earth circuit will be zero, but since the third, ninth, etc., harmonics are, for a symmetrical winding in phase

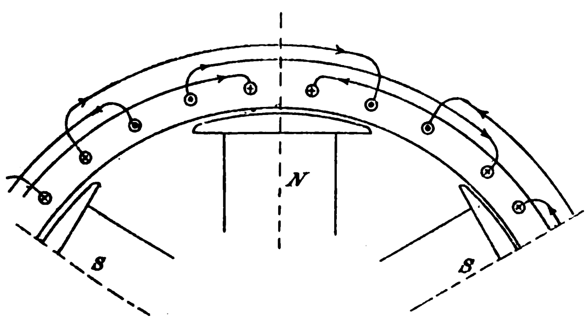


FIG. 19.

with each other they will produce currents in this circuit. The triple-frequency currents are, especially on full load, the most important, and experience shows that they are the only ones that need be considered. It may also be mentioned that in the case of a single machine working on a cable network, a third harmonic in the wave-form will cause a current

to flow through the earth connection and the capacity of the cable network; this current will only be excessive if the natural frequency of oscillation for the network happens to correspond with that of the harmonics.

Referring to the 3-phase winding shown diagrammatically in Fig. 19, if each phase carries a triple-frequency current of equal magnitude, then at the instant of maximum values the direction of these currents will be as indicated by the crossed and dotted circles. Since adjacent coils neutralise each other, the demagnetising action of the armature M.M.F. upon the main magnetic circuit will be almost negligible, so that the apparent impedance of the armature winding in so far as these currents are concerned will be very small unless the true self-inductance of the windings has an abnormally high value. This explains why very high triple-frequency currents are observed in practice, even when the wave-forms of the phase E.M.F.'s of the alternators contain relatively small third harmonics. Owing to the wide slots, long air-gaps, and small number of conductors, turbo-alter-

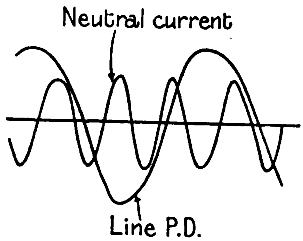


FIG. 20.

nators have a much lower reactance voltage than slow or medium speed machines designed for the same output. Hence, these triple-frequency currents will be more pronounced in turbo-alternators than in slow-speed sets, and this has been amply verified in practical working.

Professor Marchant and J. K. Catterson-Smith* have recently investigated the nature of these local currents, when two types of 2,000-k.v.a. turbo-alternators by different makers were run in parallel. The phase E.M.F. wave-forms were very nearly sinusoidal, and when analysed were to satisfy the following equations:—

$$\text{Type A}: e_a = 100 \sin pt - 7 \sin 3pt - 9 \sin 5pt,$$
$$\text{Type B}: e_b = 100 \sin pt - 3 \sin 3pt + 4 \sin 5pt,$$

the normal full-load current per phase being 200 amperes. When two machines of the same type were in parallel, the current circulating in the neutral was found to be very small, varying from 5 to 6 amperes.

* *Electrician*, vol. 63, p. 674, 1909.

When, however, a machine of type A was run in parallel with a machine of type B, the triple-frequency component of the E.M.F. was sufficient to give a current of 60 amperes through the neutral wire (see Fig. 20). It was also found that the value of the neutral-line current could be increased to 120 amperes if the excitations of the two machines were such as to make their loads of different power factors.

Besides causing additional heating in the armatures of the machines working in parallel, these currents, being practically wattless, reduce the power factor of the machines through which they circulate. When a power factor meter is connected to a machine supplying these currents, its reading may be considerably lower than that correspond-

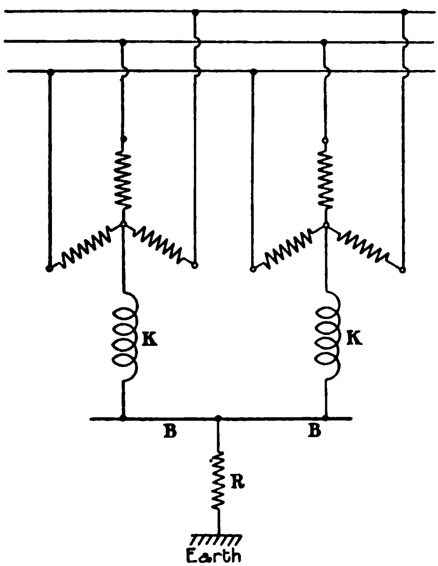


FIG. 21.

ing to the real angle of lag between the fundamental wave of terminal voltage and the fundamental wave of current. This may cause difficulty in parallel working, as the alternators would have their excitations adjusted so as to give the same reading on the power factor's meters, and this adjustment may not correspond to minimum circulating current. The method of determining the best power factor for any individual machine coupled to the busbars would be to find the excitation for which the current flowing to it through the neutral wire is a minimum.

Various methods have been adopted for getting rid of the triple-frequency currents in an earthed 3-phase system. One method (see Fig. 21) is to have the star-point of each alternator connected

through choking coils K to a busbar B.B. which is earthed through a low resistance R. The impedance of the coils K to the triple-frequency currents will be three times that offered to a current of normal frequency ; it is therefore equivalent to a resistance which falls to one-third its previous value whenever it has to carry an out-of-balance current due to a fault, and so will not interfere with the proper operation of the circuit breakers. In another method, due to J. H. Rider,* a switch is designed so as automatically to connect the neutral point of one, and only one, of a number of paralleled machines to earth. This method eliminates the triple-frequency earth currents entirely, but it is open to one objection, namely, that the neutral-points of the unearthed machines may rise to fairly high potentials, the magnitude of which depends upon the value of the triple-frequency component of E.M.F. in wave of phase voltage. A better practice than introducing choking coils or resistances in earthing circuit, is to ensure that all the machines to be worked in parallel have as nearly as possible a sine wave-form. This can, of course, be obtained by careful distribution of the stator-winding, and suitable shaping of pole-tips of the field magnet.

Discussion before the Glasgow Local Section.

Mr. Nicholson.

Mr. J. S. Nicholson : There are one or two small points in the paper which I wish to touch upon. On page 282, in dealing with free oscillations, the author says : " Free oscillations similar to the above are also set up," etc., but instead of saying they are *similar* to the above he should have said they were the same as those illustrated in the diagrams shown on page 281. On page 287 he gives a turning moment diagram for a single cylinder, double-acting steam engine. There is rather a serious mistake in this diagram. In this type of engine the turning moment must be zero at the dead-centres, that is, twice in each revolution. In fact, in most cases, due to cushioning, etc., the turning moment is negative just before the end of the strokes. It would also be better to omit the indicator diagrams from Fig. 6. As sketched they give a wrong impression of the method which is employed in determining the turning-moment diagram. I have here some curves which I think will be of interest to the meeting. Two or three weeks ago the Glasgow Corporation Tramways Department kindly gave me indicator diagrams and other necessary data relating to one of their large three-crank, reciprocating engines. We have worked out as class exercises the curves similar to those given in Figs. 11 and 12, on pages 289 and 291. The first curve represents the turning-moment diagram of the engine when working under abnormal conditions. The H.P. cylinder was doing approximately one-half of the work. The component of the superimposed oscillating torque, which has the greatest amplitude, is the second harmonic, instead of the sixth harmonic. The period T_2 of the second harmonic is 30/75 second (the engine was running at 75

* *Journal of the Institution of Electrical Engineers*, vol. 43, p. 261, 1909.

revs. per minute). The mean turning moment was $6 \cdot 25 \times 40{,}000$ lbs.-ft., and the equation of this second harmonic is approximately— Mr. Nicholson

$$M_2 = 3 \times 40{,}000 \sin (2\pi t/T_2 - 38^\circ).$$

This gives a maximum rotor displacement of $0 \cdot 64 \times 10^{-3}$ mechanical radians, or $12 \cdot 8 \times 10^{-3}$ electrical radians (see equation 8, page 292). In order to check this quantity I integrated step by step the variable portion of the actual driving torque and obtained the angular velocity curve on a time base; on integrating similarly the angular velocity curve, the curve of rotor displacement was obtained. From this curve the maximum rotor displacement was found to be $22 \cdot 7 \times 10^{-3}$ electrical radians (lead) and $19 \cdot 2 \times 10^{-3}$ electrical radians (lag) instead of $12 \cdot 8 \times 10^{-3}$ electrical radians as calculated from the very prominent second harmonic. In the last paragraph on page 288 and at the top of page 289 it is assumed that the error introduced by "substituting a sine curve instead of the irregular turning-moment curve is quite small," etc. This assumption is therefore not always justifiable. On searching for the cause of the above discrepancy in the rotor displacement I discovered the presence in the oscillating driving torque of a first harmonic of maximum amplitude approximately $1 \cdot 0 \times 40{,}000$ lbs.-ft. and of period $T_1 = \frac{60}{75}$ second. The equation to this harmonic is $m_1 = 1 \cdot 0 \times 40{,}000 \sin (2\pi t/T1 + 162^\circ)$. This harmonic would give a maximum displacement of $17 \cdot 1 \times 10^{-3}$ electrical radians, a displacement much greater than that given by the more obvious second harmonic. This greater displacement is due to the greater period of the first harmonic.

On plotting these two displacement curves in their proper phases and adding them together, a maximum displacement, lag or lead, of $20 \cdot 0 \times 10^{-3}$ electrical radians was obtained. This displacement agrees very closely with that obtained by the more laborious method of integrating the original variable turning-moment step by step. The small sixth harmonic $m_6 = 0 \cdot 26 \times 40{,}000 \sin (2\pi t/T_6 - 30^\circ)$ which was present in the turning moment had no appreciable influence on the displacement of the rotor. The above example shows the necessity for a careful consideration of the turning-moment diagram before any assumptions are made regarding the sine curve which may be substituted for the irregular oscillating torque. It should apparently have given a sixth harmonic with all other harmonics negligible in comparison, whereas the first harmonic, although not prominent, gave the greatest displacement; the second harmonic, which overshadowed all the others, gave a displacement $\frac{3}{4}$ of that of the first harmonic; and the sixth harmonic gave a displacement approximately $\frac{1}{144}$ of that of the first harmonic. On page 289 is given the turning-moment diagram for a gas engine and also a solution of the curve. I think it is practically impossible for any one to obtain the correct resolution of such a curve into its harmonics.

Mr. Day.

Mr. DAY: From the diagram Mr. Nicholson shows it would appear that the angular displacement is rather considerable. Would Mr. Nicholson therefore say if the plant referred to was running in parallel with a similar plant or whether it was running on a separate circuit? If running in parallel, can Mr. Nicholson state even approximately the amount of interchange current?

Mr. Nicholson.

Mr. NICHOLSON: The displacement there is very small; it is only 1¼ electrical degrees. The usual allowable displacement is plus and minus 3 degrees, so that it is not more than half the allowable. I imagined the displacement would have come out more, taking into account the fact that the cylinder was doing half the work.

JOURNAL

OF

The Institution of Electrical Engineers.

Founded 1871. *Incorporated* 1883.

VOL. 47. 1911. NO. 209.

Proceedings of the Five Hundred and Eighteenth Ordinary General Meeting of the Institution of Electrical Engineers, held on March 9, 1911—Mr. S. Z. DE FERRANTI, President, in the chair.

The minutes of the Ordinary General Meeting held on February 23, 1911, were taken as read, and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Hall.

The following list of transfers was announced as having been approved by the Council :—

TRANSFERS.

From the class of Associate Members to that of Members :—

Richard Borlase Matthews. | Henry Savage.

From the class of Associates to that of Members :—

Frederick Benjamin O. Hawes.

From the class of Students to that of Associate Members :—

Robert Barron.	Frank Henry H. Oakley.
Frederic Ringer Bullard.	Cyril Hunter Ryley.
Edmund Lawson.	Henry S. Scott.
Edward J. Middleton.	Anak Shore.
Leopold Geo. E. Morse.	Archibald Parker Smith.

Geo. William Williamson.

Messrs. W. Clark and F. C. Polden were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected:—

ELECTIONS.

As Associate Members.

James Cowie.
Charles Herbert Davidson.
John Ernest Hardey.
Duncan Clive M. Hume.
Henry McKenzie Kirkby.
James Brown Marr.
Arthur George Moore.
George Arthur Peck.
Reginald George Porte.
Alfred Roberts.
Adrian Hugh F. S. Simpson.
Frederick Symons.
Richard Henry Whittington.
Cecil Harry Wickham.

As Associate.

Stanley Herbert Stanley.

As Students.

Harry Oswald Addicott.
George Burton Alvey.
Reginald Charles Andersen.
William James E. Ball.
John Edwin L. Blythe.
Frederick Crossley Boa.
Phiroze Naserwanji Bogà.
Walter Bull.
Edward Vivian Cheney.
Edwin Fowler Clark.
Ernest Arthur Elliman.
George Piercy Farrer.
Enrique Penard Fernandez.
Frank Fletcher.
Richard Vernon Hansford.
Ronald Graham Hargraves.
Thomas Joseph Hornblower.
Mehmet Ichssan.
Francis Munton Jackson.
Eric Maurice Johnson.
George Christopher Marris.
Horia Toan Nadejde.
Alfred Donald Newbury.
Clifford Anthony Newell.
Joseph John Page.
Douglas Harold Payne.
Ramanathpur Ramachandra Rao.
William Pearl Richardson.
Tom Riley.
Frederick Rowcliffe.
Sidney Bertram Smith.
Henry Stevenson.
Frank Charles Tomlins.
Thomas Charles Turton.
James Warren.
Alfred Woods.

Donations to the *Library* were announced as having been received since the last meeting from Macmillan & Co., Ltd., the Newcastle and Gateshead Incorporated Chamber of Commerce, S. Hirzel, Dr. R. M. Walmsley, G. K. B. Elphinstone, H. L. Webb, J. W. Warr, W. P. Maycock, W. S. Ibbetson; to the *Building Fund* from J. H. Garratt and F. Gill; and to the *Benevolent Fund* from W. W. Cook, F. Gill, J. Gilligan, S. Insull, J. R. P. Lunn, F. H. Nicholson, to whom the thanks of the meeting were duly accorded.

The following paper, "The Laying and Maintenance of Transmission Cables," by C. Vernier, Associate Member (page 313), was read and discussed, and the meeting adjourned at 10.5 p.m.

THE LAYING AND MAINTENANCE OF TRANSMISSION CABLES.

By C. VERNIER, Associate Member.

(*Paper received January* 25, 1911. *Read before the* INSTITUTION *March* 9, 1911, *before the* NEWCASTLE LOCAL SECTION *March* 6 *and* 20, 1911, *and before the* GLASGOW LOCAL SECTION *April* 11 *and May* 16, 1911.)

When it is remembered that the mains system represents from 30 to 50 per cent. of the total capital expenditure on an electric supply undertaking,* and frequently exceeds the total cost of the plant and machinery, it is somewhat surprising that so very few papers dealing with the laying of mains have been presented before the Institution. This is, perhaps, all the more to be regretted as the subject is one upon which there is a variety of opinion as to what constitutes the best methods, and it should therefore provide good discussions. Again, it is one where mistakes may prove very costly, and a more frequent interchange of views cannot fail to be of general benefit to all concerned. It would be quite impossible to do justice to the whole subject of underground mains in any single paper, and in view of the more recent and extensive developments which have taken place in this country in the transmission of electrical energy for power purposes on a large scale, the author intends to confine his remarks to the laying and maintenance of underground transmission cables.

While America and the Continent can show longer transmissions than we have in this country, yet we are in no way behind in regard to underground work, and in one instance at least, viz., in our Northern counties, we can point to what is undoubtedly the most extensive system of underground E.H.T. cables in the world.

At this date it is scarcely necessary to consider any system other than the 3-phase alternating-current system for use on transmission schemes, as it has been almost universally adopted in all such schemes during the past ten years. The cables will, therefore, be invariably three-core paper-insulated and lead-sheathed, usually operated at pressures between 6,000 and 20,000 volts.

As this paper is concerned chiefly with the laying of these cables, it is not proposed to consider their manufacture. The author states this all the more readily as cables supplied by leading cable manufacturing firms are of a very high degree of excellence, and it is exceedingly rare

* The capital expenditure on mains of all kinds in the United Kingdom is probably not less than £25,000,000.

for breakdowns to occur as the result of faulty manufacture. Transmission cables will usually be laid on one or other of the following systems :—

1. Drawn into pipes or ducts.
2. Laid on the solid system in (*a*) wood, (*b*) earthenware, (*c*) cast-iron troughs, in each case with protective covers.
3. Steel tape or wire-armoured cables laid direct in the ground with either tile or wood plank covers.

Draw-in System.—The draw-in system has many advantages in congested districts where there is a likelihood of extensions being required along the same route, but generally it is too expensive for any extended use. While, for instance, its use might be justified, and in some cases even compulsory, in a large city, its cost would prove out of the question over a large and scattered area. Draw-in systems usually consist of separate earthenware pipes or multiple way ducts laid in concrete, with manholes spaced at suitable intervals according to the largest size of cable likely to be drawn in. Cast-iron pipes laid direct in the ground are also used, but their cost, unless the number of pipes is small, is greater than that of earthenware pipes. Bitumen fibre conduits, which are much used in America, have more recently been used in this country, and, judging from a limited experience the author has had of them, appear to provide an excellent system. The conduits are lighter to handle and more easily jointed than either earthenware pipes or ducts, and as they can be made in longer lengths the number of joints is considerably reduced. Further, on account of the flush joint, much less space is taken up and a good deal of concrete can be saved.

Single pipes provide greater safety than multiple-way ducts in the event of a short circuit taking place in the ducts. This is because instead of having a single wall of earthenware between the different ways, as in multiple-way ducts, two earthenware walls and a thickness of concrete which can be made as thick as required intervene between the different cables.

Single pipes also lend themselves much more freely to deviation singly round obstructions, without it being necessary to deviate the whole line of pipes. For these reasons multiple-way ducts are seldom used for heavy transmission work.

The design of manholes requires careful consideration, and it must be said often leaves much to be desired. It is of first importance that the cables should be so protected in the manholes that a breakdown on one cable cannot affect the other cables.

The arrangement of the cables should also be as neat as possible, and unsupported bends in the cables should be avoided. Fig. 1 shows a common type of manhole, where the cables have to be bent out of the pipes to the side walls. Accidents have occurred from manhole covers being dropped on to such cables. A much neater and safer arrangement is illustrated in Fig. 2, in which the pipes are gradually splayed out as they approach the manholes.

As far as possible, the pipe-line should not exceed two pipes in width, as otherwise the cable bend from the middle pipe is awkward to deal with. If this cannot be avoided, pilot cables and other similar less important cables should be drawn into the middle pipe or way. Manholes in wet situations should always be drained to the sewers, and where there is any likelihood of explosive gases being encountered, they should be ventilated as well.

The draw-in system does not afford the same protection to the cables as a well-laid solid system, as they are liable in certain cases to damage by chemical action from bad water draining into the ducts

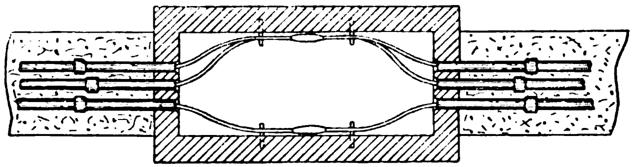


FIG. 1.

from the surrounding soil, and as the pipes are frequently wet, electrolysis is greatly facilitated.

From these points of view cast-iron pipes, where their cost is not prohibitive, are to be preferred, as they can much more easily be made watertight by means of leaded joints, and if made electrically continuous throughout will act as a protection to the cables from electrolysis. The cables should be bonded to the pipes in a substantial manner at each manhole, and any electrolytic corrosion likely to occur will take place on the pipes, and the life of the cables thus be greatly ncreased. If E.H.T. cables are drawn into earthenware pipes or

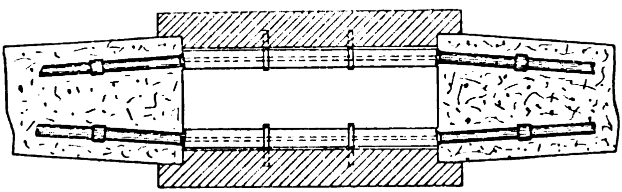


FIG. 2.

ducts, it is preferable to use wire-armoured cables, the armouring taking the place of the copper tape B.O.T. earth sheath under the lead, as this armouring and the protective coverings will add considerably to the life of the cables. Failing this, it is an advantage to use cable taped and braided over the lead sheath, as plain lead-covered cables are not sufficiently protected against chemical or electrolytic corrosion likely to be encountered.

All cable armourings and lead sheaths should be carefully bonded together, and also earthed to an earth-plate at each manhole. One

advantage sometimes claimed for the draw-in system is the facility for the carrying out of repairs, as it is only necessary to draw in a new length of cable. Those, however, who have had experience of repairs on both drawn-in and solid systems of cables will have no difficulty in agreeing that this is a doubtful advantage, as it is necessary in every case to draw in a whole length of cable between manholes in order to effect a repair, whereas on a solid system cases seldom occur where it is necessary to insert more than a few yards of cable.

Solid System.—E.H.T. cables when laid on the solid system are usually laid in either wood, earthenware, or cast-iron troughing filled in with a waterproof composition. There is very little difference in the cost of wood and earthenware troughing, and in many cases earthenware troughs can be obtained more cheaply. Earthenware, needless to say, is a much more lasting material than wood, and may be expected to outlast any cables which may be laid within it. The life of wood troughing, on the other hand, varies greatly, according to the kind of ground in which it is laid. It is usually greater when laid in wet clay than when it is laid in sand or ashes, owing, no doubt, to

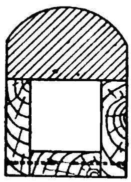


FIG. 3.

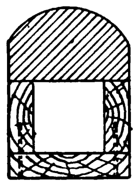


FIG. 4.

the exclusion of air. Opinions differ as to the preservative treatment to be used for the wood. Some object to creosoting, and specify that the troughing shall be treated with Stockholm tar. When this is the case, the usual method is to boil the troughing in the tar, but too often the makers will only soak the wood in cold tar, or the tar may even be put on like paint with a brush. When creosoting is ordered, frequently similar methods are used, and only a mere covering of the surface is obtained. In the author's opinion, the only satisfactory treatment is to impregnate the timber with creosote under pressure, as is done in the case of telegraph poles. Those who object to creosoting generally do so on the ground of possible chemical action on the lead of the cables, or again to a slight dissolving action which the creosote has upon the pitch or bitumen filling. Creosote obtained as a by-product of coal-tar distillation, if otherwise free from foreign matter, has no action upon lead or iron, but wood creosote obtained in the distillation of wood must be carefully avoided. The action upon the pitch filling is frequently absent, or so slight as to be negligible, but in any case is not at all a disadvantage, as it increases the adherence of the pitch to the troughs.

It is well to allow the surplus creosote to drain off before the

troughs are used, and no trouble need be expected in this direction. Wood troughing is not brittle like earthenware, and can be obtained in much longer lengths, thus decreasing the number of trough joints, and as these features are its only advantages, earthenware troughing is much to be preferred, except for situations where much vibration is to be expected, as in the case of cables laid along railways.

The construction of wood troughing is very frequently carried out in a wrong way, as shown in Fig. 3.

It will be noticed that the sides of the troughs are nailed to the bottom strip, and thus the weight of the soil above comes upon the nails which, in any case, quickly rust. It is frequently stated that the filling composition also acts as a support, but all filling compositions must be looked upon as fluids under long-continued pressure. Fig. 4 shows the correct method of building up wood troughing, in which it will be observed that the weight of the soil on the side-pieces is distributed on the bottom piece. Figs. 5 and 6 show various methods of jointing successive trough lengths.

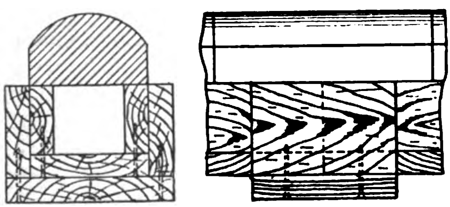


FIG. 5.

Earthenware troughing should be well glazed outside, but left unglazed inside. Pitch or bitumen does not adhere to a glazed surface, and this leaves room for moisture to creep in between the filling compound and the troughing. This is not the case with earthenware troughing which is unglazed inside, as the compound adheres closely to the rough surface. As already mentioned, the chief objection to earthenware troughing is the short lengths (about 2 ft.) in which it has to be manufactured, but in good ground this gives no trouble.

Cast-iron troughing is expensive, but makes a thoroughly sound system provided the bonding of the separate lengths of troughing is carried out in a thorough and substantial manner. The mere bolting of the troughs together, as is often done, is of very little use for this purpose. The lead sheath and cable armouring (if any) should be well bonded to the troughs at intervals, and in some cases iron supporting bridges are used which grip the cable and are screwed to the iron troughs.

Before leaving the question of troughing, it should also be mentioned that asphalt troughing is occasionally used. This consists of an asphalt-lined sheet steel trough in which the cables are

laid with bitumen. The usual cover consists of an asphaltic concrete, which further prevents the access of moisture to the inside of the trough. As the author has not had personal experience of it, he does not propose to discuss it further, but its chief point of interest lies in the claim which is made that cables laid on this system have their metallic sheaths perfectly insulated from earth. Cables laid on this system are also free from bridge troubles (which will be dealt with later) as with this troughing bridges can be dispensed with altogether.

The next point to consider in connection with the solid system is the filling compound. This is usually refined pitch, freed from any matter which might act chemically on lead or iron; or again, less frequently, Trinidad bitumen is used. Trinidad bitumen is two and a half to three times as costly as pitch, hence pitch is more often used; but there can be no doubt of the superiority of the former for cable laying. Pitch cannot be used in its natural state, as it is too brittle and has to be mixed in suitable proportions with a thinning oil in order to render it more plastic. The greater the proportion of oil the softer and more flexible the pitch. Unless therefore very great supervision is exercised in the mixing of the pitch and oil in the correct proportions (always a difficult matter) the pitch will be too brittle, and from his experience the author inclines to the opinion that pitch which has been put into the troughs mixed with thinning oil in such proportions as to be quite plastic does not retain this property indefinitely. Bitumen, on the other hand, is, in its natural state, a more tacky material, and it has the advantage of adhering more closely to the lead sheaths of cables and to the troughing.

The weakest part of the solid system is the supporting bridges for the cables. These were, until quite recently, made of wood, sometimes treated with preservative composition (generally Stockholm tar), and in some cases not treated at all. At first sight it would scarcely seem possible for cable bridges which are surrounded with pitch to absorb moisture, but after cables have been laid some time it is quite common to find the wood bridges wet.

Wood should never be used in contact with the lead sheath of cables, as in its decay, which must inevitably occur sooner or later, organic acids are produced which attack lead. This effect is more serious with some woods than others, oak being particularly bad in this respect. Cable bridges should therefore be made of earthenware, china, asphalt, or some other material not subject to absorption of moisture or to decay, and which is chemically inert.

All bushes required at trough and pipe ends should be of glazed earthenware, and this applies even more strongly to draw-in systems where such bushes are exposed to air and moisture, which greatly facilitate chemical action. Similarly all organic materials such as canvas, waste, etc., should be strictly kept clear of lead sheaths. Certain makes of cement also act chemically upon lead, and some engineers who have used conduits consisting of cement-lined steel tubes have experienced trouble from this cause. Asphalt bridges

have the advantage that the hot filling composition softens their surface and thus adheres very closely to them. This property is sometimes a disadvantage with heavy cables, as the bridges are liable to soften sufficiently to be crushed out of shape by the weight of the cables. This is not the case with the smaller sizes of cables, and for these probably no more suitable material can be employed. For heavy transmission cables the author prefers glazed earthenware bridges, and, in order to ensure the adherence of the filling composition, it is his usual practice to prepare the bridges by dipping them when dry in a fluid mixture of pitch and thinning oil, with which they become coated. This ensures adherence of the filling composition, as when it is run in, the thin coating, which has in the first place been put on to perfectly dry bridges, melts and the two surfaces adhere. Without this precaution, if the surface of the earthenware is at all wet, or even damp, the filling composition will fail to adhere. Figs. 7 and 8 shows designs of cable bridges, from which it will be noticed that the surfaces in contact with the troughs are reduced to mere points, so as to allow the filling composition entirely to surround them. The

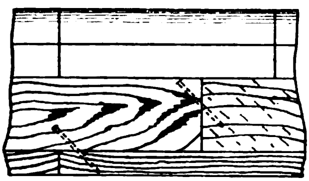


FIG. 6.

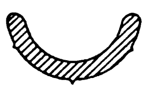


FIG. 7.

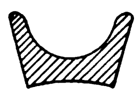


FIG. 8.

adherence of the filling material to the cables and to the troughs has already been mentioned. Pitch does not always adhere to plain lead-covered cables, especially if there is any moisture on the lead. Its melting-point being about half that of bitumen, it is also more liable to become chilled against the lead sheath, and it is frequently possible to break it off in flakes which retain the moulded shape of the cable and show the existence of a space between. Some engineers use cables with a braided covering for laying on the solid system, and this is much to be preferred, as the filling composition adheres very closely to such braidings. Others, again, lay armoured and jute served cables solid, and this may be considered the very best solid system of cables obtainable, especially if bitumen is used.

A good hard-pressed dome-shaped tile about 3 in. thick cannot be excelled as a protective covering for transmission cables, whether laid in wood, earthenware, or cast-iron troughing. Cast-iron covers, about ¼ in. thick, such as are often used, do not offer sufficient protection to a blow from a sharp pick. The dome shape is the best to glance off a pick point, and it is a good plan to have the tiles stamped either with the name of the owners or with the word "electricity," which act as a warning to excavators of what the troughing contains.

It may further be remarked in passing that conduits when laid in concrete are much more liable than troughs to external damage. A block of concrete encountered in the course of excavations seems to offer an irresistible temptation to the ordinary excavator to set about its immediate removal with hammer and wedge. The method of indicating conduits shown in Fig. 9 is useful in such cases, particularly where conduits are laid across roadways which have a concrete foundation.

The solid system is not, in the author's opinion (who has had some twelve years experience of it), a thoroughly practical system to use for transmission work or any similar work on a large scale. While in theory it appears an ideal system, the practical difficulties in obtaining good workmanship in the conditions under which the work has to be carried out are very great, particularly in our uncertain climate. A shower of rain will frequently saturate everything—cable, troughs, bridges, etc.—while in dry windy weather dust and dirt get blown into the troughs. In waterlogged ground it is practically impossible to

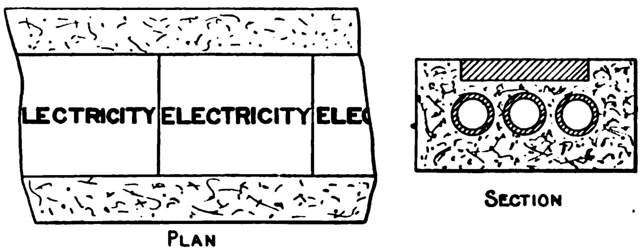


FIG. 9.

obtain good work, and owing to the shrinkage of the filling compositions the greatest care has to be exercised in order to get the troughs full and also free from blow-holes. The system has also very serious disadvantages attending on its great rigidity, which will be considered later.

Armoured Cables.—Cables are usually armoured with two overlapping layers of steel tape or with a single or double layer of armouring wires. Wire armouring is used in cases where tensile strength is required, and for transmission cables this type of cable is much to be preferred, for reasons which will be considered further in connection with subsidence and vibration troubles. Armoured cables (unless used solely to comply with the Board of Trade earth sheath regulation on the solid system) are usually laid direct in the ground, with a protective covering which consists of either tiles or creosoted planks about 2 in. thick, laid directly over the cables with about 3 in. of soil in between. Creosoted planks are considered more satisfactory, as tiles are very liable to be displaced and removed in the course of excavation near the cables by other companies. This is not the case with planks, as unless the full length of the plank, 12 to 14 ft., is opened up, they cannot be removed, and

wood gives a better warning. Further, a blow from a pick cannot displace them as in the case of a tile, and wood withstands many blows from a pick before it is penetrated. Armoured cables as generally supplied do not offer as good a protection from chemical action in bad ground as a properly laid solid system. The protective coverings usually consist of a serving of impregnated jute direct on the lead sheath, then the armouring and another serving of jute over this, the cable finally being passed through a bath of hot compound. These jute coverings eventually become sodden in wet ground, and this and any chemical matter with which it may be charged in some cases very quickly destroy the armouring and attack the lead. The popularity of the solid system in this country may be almost entirely attributed to some very rapid failures of armoured cable systems which have been experienced in the past. Armoured cables laid in dry sandy soils give very good results, while similar cables laid in made-up ground where decomposition of organic matter is liable to occur, or in ashes or in ground charged with sewerage matter, sometimes fail within a year or two, and in some cases even more rapidly.

It is the practice on the Continent to surround armoured cables with sand when other kinds of soil are encountered, and this has also been done in some cases in this country. This method adds very seriously to the cost of the work, as it is not only necessary to bring sand to the work, but also to cart away larger quantities of surplus soil. It is questionable whether a layer of sand is altogether an advantage except in very dry ground, which is more common on the Continent, as if there is any water about the bed of sand will act as a drain and keep the cable continually wet. Clay has been said to affect armoured cables injuriously, but this has not been the author's experience, although the soil in his district consists almost entirely of clay, and in bad soils it is better to surround the cables with well punned clay.

In dealing with the solid system, it has been pointed out that it has many objections for transmission work on a large scale, the chief of which is the difficulty of getting the work done satisfactorily under adverse conditions of weather and similar inconveniences encountered when carrying on outdoor work on a large scale. This and the great rigidity of the system when laid, which gives rise to troubles arising from vibration, subsidence of the ground, and earth movements, render the use of armoured cables, which are better able to meet these conditions, almost imperative. Attention has therefore in some cases been directed to the improvement of the protective coverings on armoured cables, with an endeavour to render these coverings as good a protection to the cables as a good solid system, but with the very important advantage that the work can be carried out in the cable makers' shops under careful supervision and without any consideration of weather.

The improved coverings adopted, and which are now provided on all armoured cables laid by the power companies operating on the North-East coast, consist first of a layer of a flexible bitumen compound

$\frac{1}{10}$ in. thick coated directly on to the lead and served over all with two specially closely woven bitumen impregnated tapes. The cable is then served over these tapes with compounded jute yarn to form a bed for the armour, after which the armouring, either of steel tapes or wires previously passed through a bath of waterproof composition, is put on. This armouring is then served with jute yarn, passed through a bath of hot compound, and finally lime washed.

The total cost of the specially protected armoured cables when laid is very little more than the cost of plain lead-covered cables laid on the solid system, and with this slight extra expense a much more suitable system is obtained.

The Jointing of E.H.T. Cables.—The satisfactory jointing of cables is the most important operation in connection with cable laying. Even badly laid cables will often run satisfactorily for years, but badly designed joints, and especially joints of inferior workmanship, will prove a sure and constant source of trouble. The idea still commonly prevails that joint breakdowns must be taken in a philosophical manner as one of those things which are always with us and cannot be avoided. Joint breakdowns are, however, inexcusable at the present day, and any breakdowns caused by bad workmanship on the part of jointers should be severely dealt with. So much does reliable jointing rest in the hands of the jointer, that only thoroughly skilled men with a long period of training should be employed on important work like transmission cables. Again, workmanship being such an important factor in jointing, all improvements in design should tend to such simplification of the work as will diminish the necessity for this great skill.

In the design of E.H.T. joints there are three essential points which require careful consideration, viz.:—

1. The jointing of the conductors.
2. The insulation of the joint.
3. The making of the joint watertight.

With regard to the first point, the jointing of the conductors is usually carried out by inserting these conductors into a short copper tube, the joint being afterwards soldered. This form of joint is often very inferior. It is seldom that the tubes fit the conductors, and any sort of a fit is often considered good enough, as the joint will afterwards be soldered. In transmission work, however, the cables are capable of considerable overloading, and can safely be run continuously up to a temperature of about 150° F. Overloading and unloading of the cables throws a great strain on the joints, owing to the expansion and contraction of the conductors due to changes of load, and joints with poor contacts heat up and frequently pull out. The copper tubes or ferrules are sometimes split in two halves, bound together at each end, so as to tighten on the conductors, or again split on one side only to allow of being closed up to fit. As the shape of conductor used in three-core cables is seldom round, but approximately triangular in what is known as the "clover leaf" cable, round tubes can scarcely

be expected to make a satisfactory joint, except possibly with very small cables, which can be pinched to a circular shape. Because of this, many engineers specify that the conductor cores must be telescoped together. This form of joint, unfortunately, while a very great improvement from the point of view of electrical contact, is mechanically about the weakest joint which it is possible to use.

The author having given much attention to this question, recently devised a new method of jointing* which overcomes these disadvantages, and which, in its construction, is so simple as to ensure sound joints without the exercise of any great skill.

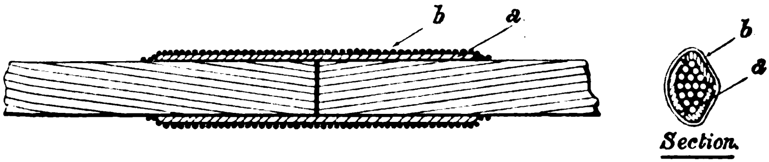


FIG. 10.

The method of jointing, which is illustrated in Fig. 10, consists in using strips of flexible copper braid (*a*) which are laid longitudinally along the conductors, and which are bound down on to them tightly by a circular binding of copper wire (*b*), the joint being afterwards soldered.

Joints of this type give a greatly increased electrical contact, as the flexible braid is compressed tightly into all the interstices of the conductor strand, and in proof of this it may be mentioned that a joint of this type made as in Fig. 10 and left unsoldered required one-third of a ton merely to pull one of the conductors out of the braids. A similar joint again unsoldered was run up gradually to 7,000 amperes per square

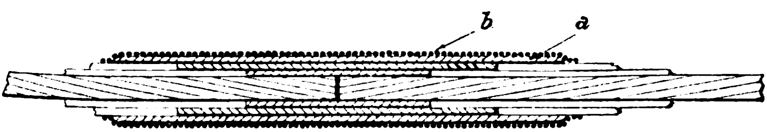


FIG. 11.

inch, its temperature rise being at all times lower than that of the conductor.

Fig. 11 shows an alternative type of this joint for heavier conductors, which consists of more than three strands of wires. In this it will be noticed that the continuity of each strand can be maintained independently by separate layers of copper braid. The copper braid when soldered and dissected can scarcely be distinguished from solid copper, so thoroughly does it become filled with the solder which it holds like a sponge.

* Patent No. 15413 of 1909.

The second point for consideration is the insulating of E.H.T. joints. Figs. 12 and 13 show the two representative types of joints generally used for all working pressures up to 20,000 volts. Each of these two types have special features, which it is important to consider in some detail, and the remarks which follow must be understood to refer especially to joints for 20,000 volts. At such high pressures the weaknesses of joints reveal themselves, and, as it should always be the ultimate object of the designer to construct joints which are in every way equivalent to the cable itself in regard to reliability, the experience obtained at the higher pressures may with advantage be extended to the construction of joints for lower pressures, *i.e.*, from 6,000 volts upwards.

The insulation of joints may be provided in either of two methods, first by putting insulation on the conductors themselves, or by spacing them apart and using the filling composition as the sole insulating material. Fig. 12 shows a joint of the former type, in which the cores are in contact after each having been separately insulated by wrapping them up with an insulating tape. White linen tape boiled in resin oil just before using is more generally used, but in some cases tapes impregnated with special compounds at the factory have been used. These latter tapes cannot, however, compare with the former, as all tapes are liable to absorb moisture, and by boiling the tape in oil just at the time it is required all moisture can be extracted with certainty. Insulating tapes boiled in this manner are also saturated with oil, which is squeezed out in the process of wrapping on and fills all crevices between layers. Factory impregnated tapes are of a drier nature, and do not possess this feature. This, moreover, is an extremely important feature, as in E.H.T. joints the breakdown pressure is enormously reduced if air is present. When E.H.T. joints were first insulated in this way, it was a common practice to insert thin sheets of mica in between the wrappings of tape. It has, however, been found that joints insulated with tape and mica, notwithstanding the very great dielectric strength of the latter material, gave very much lower breakdown pressures than joints insulated with tape only. The difference is attributed entirely to the greater absence of air in the latter case.

The three cores, after each being separately insulated, are taped over together by another wrapping of insulating tape over their whole length in order to provide the same thickness of insulation between cores and earth as between the cores themselves.

In the second type of joint (Fig. 13), the conductors are separated from one another by an insulating spreader or separator, which may be either of ebonite, china, or similar material. The cores are sometimes taped over with insulating tapes, but with certain precautions this is not necessary and is best avoided.

High-grade joint-box compounds possess very high dielectric strength and withstand higher breakdown pressures than insulating tapes, but their great disadvantage is the considerable shrinkage which takes place on cooling, and the liability, if of a solid nature, for blow-

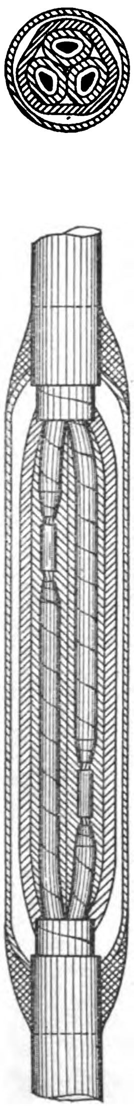


Fig. 12.

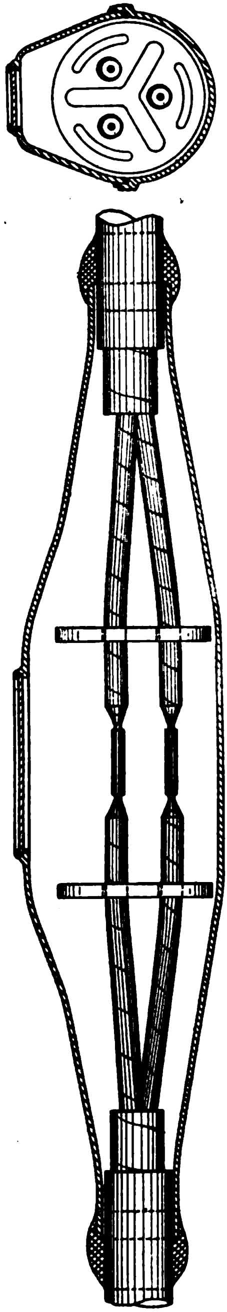


Fig. 13.

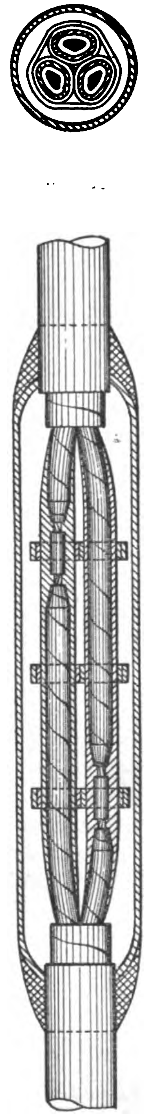


Fig. 14.

holes or air-pockets to form in their mass. The great importance of excluding air from all parts of E.H.T. joints has already been stated, and the two types of joints (Figs. 12 and 13) may now be considered from this point of view.

Joints of either type may be filled either with an insulating oil or a joint-box compound (of a solid or viscous nature). Oil is objected to by many engineers, who fear its being absorbed up the cores of the cables, and who therefore insist on a joint-box compound being used. Although one hears this absorption of the oil frequently mentioned, the author has yet to meet a case where a breakdown has occurred from this cause, and with cables impregnated under vacuum, as E.H.T. cables always are, the leakage should in any case be very small. The author considers it important that a joint insulated in the manner shown in Fig. 12 should be filled with an oil, and that the outer insulation over the three cores should be put on in the form of bands at intervals along the cores, as in Fig. 14, rather than wrapped over the whole length of the cores, as this, especially if a solid joint-box compound be used, will leave large air-spaces all round the cores which the compound cannot penetrate, and there is further a danger of the oil drying out of the insulating tapes. The cores should also be separated at intervals by similar bands of insulating tape, so as to allow the greatest possible freedom of access to the oil, which will keep the insulating tapes constantly impregnated, and this will be greatly assisted by the constant temperature changes which the cable undergoes under changes of load.

Considering the second type of joint (Fig. 13), in which the spacing of the conductors by means of insulating separators, together with the filling compound, is relied upon to provide the insulation of the joints; in cases where solid joint-box compounds have been used breakdowns have occurred due to shrinkage of the compound taking place in solidification after the joints have been filled. In large joint boxes of this sort the cooling takes place from the outside to the inside, so that the final shrinkage takes place in the centre of the mass of compound. The outer layers being already set before the centre part of the joint has solidified, the shrinkage tends to produce a vacuum, and if there were no air available a hole would form with a vacuum inside. It has been found, however, that there is always a certain amount of air present in the cores and insulation of the cable, due to the impregnating oils of the cables running out when the cable is cut, and also being dried out by the heat in soldering the joints. The net result of this is that the hole due to shrinkage always forms at the ends of the cores and draws out air from the cores. This air-pocket causes breakdowns of the joints due to sparking, which takes place from core to core across this air-space. By insulating the cores separately with insulating tapes before the joint compound is run in, this drawing out of air from the cores can be avoided, and breakdowns from this cause prevented. The objection to having oil-impregnated tapes surrounded by a solid compound which does not keep the tapes impregnated still

exists, however, and for this reason an oil filling should in such cases be used. With an oil, it is again objected that it may leak away up the cores of the cable, and on this account in a joint of this type the author prefers that the cores should not be taped over, and that a viscous joint-box compound be used which never sets and in which cavities cannot form. It should be said, however, that an insulating oil could be employed, provided the question of possible leakage from the joint box is guarded against. It has been proposed by one large firm to exhaust such joints by a vacuum pump previous to running in the oil, and this will no doubt effectually provide perfect insulation for all pressures and also prevent any possibility of leakage up the cable cores.*

Comparing both types of joints from the point of view of skill required in making them, joints of the type Fig. 13 have the advantage in this respect, as the conductors are well apart, and it is only a question of the right kind of filling composition being used. A weak point, however, is the insulating separators, which in some cases have caused breakdowns, due either to moisture on their surface or to a film of air arising from imperfect adherence of the filling compound, the joints breaking down to earth *viâ* this surface.

In joints of the type shown in Fig. 12, where the cores are in contact, breakdowns are certain if the jointer does not pay careful attention to the extraction of moisture from the insulating tapes; or if he does not put on a sufficient thickness; or, again, wraps it on in a slovenly manner.

A joint which the author considers more reliable than either of the two types already discussed, and one which, moreover, does not call for such great skill on the part of the jointer, is illustrated in Fig. 15. In this type of joint the insulation is provided by loosely fitting tubes, preferably micanite, which are sprung over the cores, the conductor joint being left bare inside them and the tubes overlapping some distance over the ordinary paper insulation at each end. The tubes, which are split on one side with a lap joint, are finally taped over their whole length with two layers of insulating tape to keep them together, and the three tubes are separated by star-shaped china pieces taped down to them, which keep them apart and centre them in the lead sleeve. This lead sleeve is then filled in with the insulating composition, either an oil or a viscous joint-box compound—preferably the latter—which can run into the tubes and all parts of the joint box. It is important to space the china separators as far as possible from the ends of the tubes, so as to increase the leakage path between cores and to earth. It will be seen that in a joint of this type the risk of puncture between cores, as in Fig. 12, is avoided, the workmanship is of the simplest description, and with a suitable joint box compound breakdowns are not likely to be caused by air.

Such a compound must be viscous and of about the consistency of thick cream at ordinary temperatures. When heated it should run as freely as heated oil, so as to penetrate all crevices, and it must

* *Electrician*, vol. 66, p. 962, 1911.

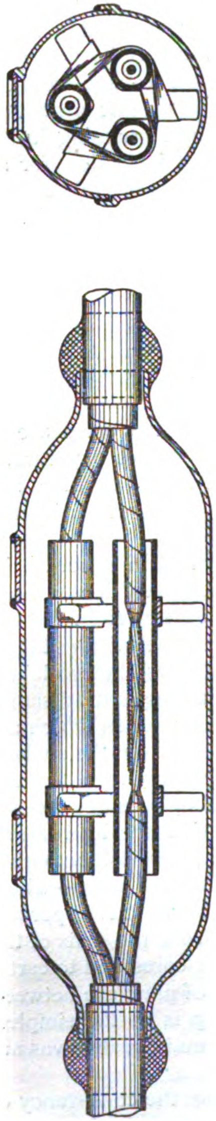


Fig. 15.

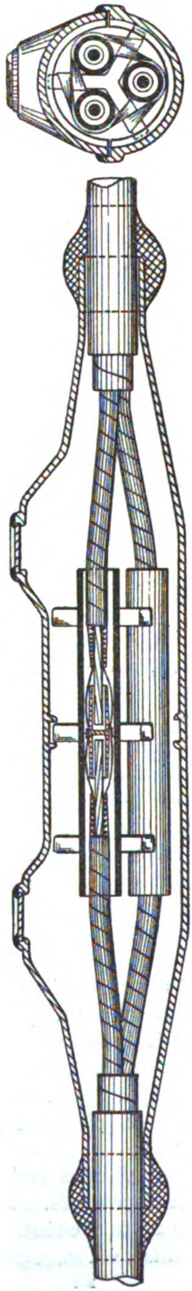


Fig. 16.

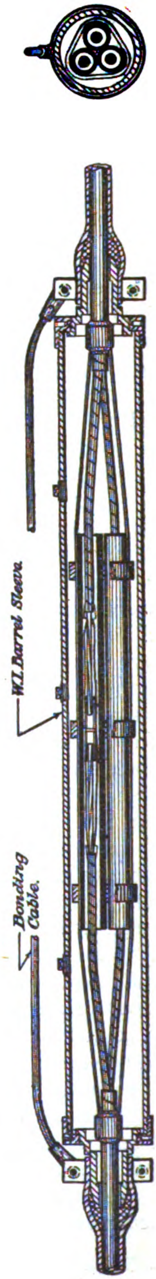


Fig. 18.

retain these features throughout its life; that is, it must remain a perfect mixture, and not be liable to have its thinning constituents, oil, and such like, separating out from the body of the compound, which consists usually of bitumen or resinous compounds.

Oils such as resin or other cable impregnating oils have been frequently referred to as suitable filling compounds; but if they are used they must always be carefully freed from all moisture before use, as oils frequently contain and absorb moisture from the atmosphere.

The third and last point on this question of jointing is that of the containing sleeve, and the making of the joint watertight. Lead sleeves are almost exclusively used in this country on E.H.T. cables, and are wiped on to the lead of the cable at each end and at all joints in the sleeve itself. Sleeves made out of drawn lead piping

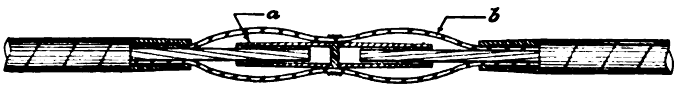


FIG. 17.

(Fig. 12) are perhaps in greater favour, as sleeves of any length can be readily obtained, and they only require a wipe at each end. Cast-lead sleeves (Fig. 13) are less frequently used, and even less frequently cast-iron joint boxes are used. With the latter all joints in the castings should be faced to make them watertight, and the box should be bonded across by a bonding cable to maintain the continuity of the lead sheath across the joint box. This is necessary, as brass glands to which the cables are wiped are screwed in at each end of the cast-iron box, and these screw threads should not be relied on for electrical continuity. Another type of sleeve more recently used consists of a wrought-iron barrel, and is shown in Fig. 18, and should be similarly bonded across.

Lead sleeves provide for electrical continuity through the lead wiping, and require no further bonds, except with armoured cables, in order to maintain the electrical continuity of the armouring. It is usual to enclose all joint boxes in an external wood or earthenware box filled in with pitch or bitumen, which acts as a protection against corrosion.

Usual Causes of Breakdowns.—Beside faulty workmanship, these may be generally summarised as follows:—

1. External damage.
2. Chemical action.
3. Electrolysis.
4. Subsidences and earth movements.
5. Overrunning.
6. Vibration.
7. Pressure surges.

External Damage.—Breakdowns due to external damage are generally due to injury caused in the carrying out of excavations by other undertakers. These may result in picks or crowbars being accidentally driven into the cables, or, in the case of solid systems, to damage caused by undermining of the cables without properly filling in the ground afterwards. The author may have been more fortunate than others, but such cases have been rare in his experience, and would not average one case per annum over the past ten years. Other still less frequent cases of breakdowns due to external causes which the author has experienced, are leakage of steam and hot water from steam pipes in the neighbourhood of collieries and shipyards, destruction of the lead sheath by vermin, collapse of a dock retaining wall, and undermining of cables by leakage of water from water mains.

Chemical Action.—Chemical action, where care is taken in carrying out the work of laying the cables, should seldom cause any trouble. All material used in the work, such as pitch, oils, compounds, and linen tapes, as well as any suspicious water or soil encountered, should be submitted to a chemist for examination, and it may be remarked that in perhaps no branch of engineering work is there greater need for close co-operation between the chemist and the engineer. It is important to remember that once cables are laid down there is no opportunity of remedying mistakes except at very great cost, and that cables are laid down and expected to last for at least twenty to thirty years without inspection and with the minimum of attention.

Electrolysis.—Electrolysis on lead-covered cables is much more likely to give serious trouble before it is discovered, and is difficult to guard against, as the conditions which give rise to it may change frequently without any warning. Where bad cases of electrolysis have occurred it has generally been found to be due to excessive leakage from tramway undertakings or similarly from 3-wire continuous-current networks. When this excessive leakage has been removed and the Board of Trade regulations complied with, electrolysis has been greatly minimised, if not altogether prevented. Much more can be done in this way than by earthing or insulating the lead sheath, as is frequently done, although these additional precautions will assist in preventing corrosion. The whole question is very much simplified on transmission cables by the cables being as a rule few in number and following definite routes, whereas on an extensive lead-covered low-tension network with all the lead sheaths bonded together and covering a large interconnected area it is a much more difficult matter to deal with. Considering a transmission cable several miles in length, the danger zones can be pretty well clearly defined. Such a cable may possibly pass through a large city supplied with a 3-wire network and electric tramways, then pass on to a purely country district, and again into another tramway system. Tests can therefore be made at various points and evidence obtained of any conditions existing which are likely to cause electrolysis.

Apart from this, there are at least two well-defined and opposite

views on the question of the safeguarding of cable sheaths from the effects of electrolytic corrosion, which are—

1. Earthing the lead sheath to earth-plates at frequent intervals.
2. Insulating the lead sheath from earth.

The principle underlying the first method is that a number of good metallic conducting paths should be provided at frequent intervals by means of which any current which gets on to the lead sheath may flow to earth instead of leaving the lead sheath through unintentional leakage paths, at which points corrosion will be set up.

Unfortunately, a low-resistance earth is most difficult to obtain with any type of earth-plate, and this difficulty is further aggravated by the extreme difficulty of getting any permanent insulation of the lead sheath to earth along the remainder of the route with any of the usual systems of laying. Practically all lead sheaths, whether laid on the draw-in, solid, or armoured systems, will test "dead earth" shortly after, if not at the time of laying. It is therefore a question of which path offers the lowest resistance to leakage currents, either the earth-plate or some other leakage path (such as at bridges, bends, and ducts) between the lead sheath and earth. If the latter, then current may leave at such places and set up corrosion.

The second alternative view—that of insulating the lead sheath from earth—is claimed for such systems as the Howard asphalte solid system and also bitumen fibre conduits. How far such systems are successful in this direction it would be interesting to know from actual users and from tests made a few years after laying. It cannot be overlooked, however, that even if the insulation is not perfect with such systems a combination of them with earth-plates at intervals would prove of considerable advantage, as what is required in thus earthing the lead sheath at intervals is that the resistance of this lead sheath to earth should at any point along the route be considerably greater than that of the earth-plates, including the resistance of the lead sheath itself between such earth-plates. Before leaving this question reference should be made to Messrs. J. G. and R. G. Cunliffe's paper on "Electric Traction Vagabond Currents," * in which it is pointed out that electrolysis is chiefly confined to metal pipes and cables laid within 3 ft. of tramway rails, and the author's experience, where the Board of Trade regulations have been adhered to, would seem to confirm this, but practically every case which has come to his notice has been due to neglect of these regulations.

Subsidences and Overrunning.—The next cause of breakdown to be considered is that of subsidences and earth movements, together with which the question of overrunning may also be considered, as all give rise similarly to expansion and contraction of the cables. Undertakers operating in colliery and other mining districts at times experience serious trouble from the pulling out of joints or cable breakdowns due

* *Journal of the Institution of Electrical Engineers*, vol. 43, p. 449, 1909.

to subsidence of earth movements. These are much more frequent on solid laid cables than on either drawn in or armoured cables, although none of these systems can be said to be altogether free from this trouble. Sometimes the opposite effect, viz., that of compression of joints or of cable bursts, is met with.

When the ground subsides, the lead sheath offers little resistance, and is able to stretch quite easily, and provided the movement is not too sudden, it is in most cases unaffected. The conductors, however, do not stretch, with the result that a great strain is put upon them, and the conductor joints being generally the weakest point, these joints pull apart. It has been found that laying the cable with slack or snaked in the ground will not prevent this occurring, unless this snaking is done quite loosely in an empty trough, so that the cable can pull quite freely over long distances. The conductors will transmit the stress upon them to the joints quite easily round bends, or any waving in the cables after the manner of the wire in the Bowden brake commonly used on cycles. Cases of compression are generally caused by earth movements, which in some cases are quite extraordinary. Cables have been known to have a particular joint pulled out at one time and compressed shortly afterwards. In order to overcome troubles of this sort, the author has designed* an expansion type of joint which is illustrated in different types of sleeves in Figs. 16 and 18. The method of jointing the conductors is shown on a larger scale in Fig. 17 and consists of a guide tube (*a*) in which the conductor ends can slide freely, the electrical continuity of the conductors being maintained by strips of flexible copper braid (*b*), which are bound down to them at each side and to the guide tube in the centre in order to maintain the relative positions of the working parts. The insulation of the joint is on the lines already advocated and shown in Fig. 15, and need not therefore be described further. The joint is finally filled with a viscous joint-box compound, which does not interfere with the movement of the various parts. Joints of this type have been in use for about eighteen months on several 20,000-volt cables on the power companies' systems in the Newcastle district, and have given very good results, no breakdowns of the joints or of the cables having occurred since their installation, although previous to this such breakdowns were very frequent. Joints opened up for inspection have shown movements of over 2 in. to have taken place, in some cases, in a few weeks. The latest joints installed provide for 6 in. movement in all, but joints can be made for much greater limits of movement if required.

It is important that all joints in the affected area should be of the expansion type, and it is not sufficient to insert such joints only at intervals, leaving ordinary non-expansion joints in between, as the latter will almost certainly be affected, notwithstanding the expansion joints on either side.

Again, transmission cables are at times loaded up to very high-

* Patent No. 12146 of 1909.

current densities, either in cases of emergency or in order to defer the incurring of heavy capital expenditure in laying additional cables. This matter has already been referred to under the jointing of the conductors, in which the great strains which come upon the joints in such cases have been pointed out, but the actual expansion and contraction which takes place in cables needs emphasising, as this is frequently overlooked. Assuming a cable is laid in the ground and jointed up originally at a temperature of 60° F.,* with a safe increase of temperature of 90° F., the conductors will expand 4 ft. 6 in. in a mile. The lead would, under similar conditions, expand 7 ft. 4 in.; but its temperature in the first place will always be lower than that of the conductors owing to the larger radiating surface, and again it will adjust itself to the expansion and contraction of the conductors owing to its ductility. It is somewhat surprising that means for taking up such movements are not usually employed on cables, as is done on practically every engineering structure and on pipes, although in these cases the changes of temperature are nothing like so great. For these reasons the author strongly favours the insertion of expansion joints on all transmission cables, which will enable such cables to be run up to any current density which the paper insulation will stand, with the certainty that the joints will not fail at a critical time. It should again be noticed that the solid system is not one which adapts itself to such expansion and contraction movements.

Vibration.—Power and railway companies who have cables laid alongside railway lines frequently experience breakdowns caused by the breaking of the lead sheath due to vibration from passing traffic. This source of trouble seems to be confined entirely to cables laid on the solid system, and takes place at the joints of the troughing. The vibration produces, first of all, crystallisation of the lead at these points, and finally the lead breaks through. The smaller the cable the more severe is the trouble, and even if a small cable and a large one be laid alongside one another in the same trench, the small one will always fail first. This would appear to be due to small cables being set into vibrations of greater amplitude owing to their smaller weight, but no doubt it is only a question of time before the larger ones also fail. Although it might be supposed that very great vibration such as may be expected on railways is necessary before this trouble occurs, serious cases have occurred on lead-covered cables laid within 2 ft. of tramways which were laid on a bed of concrete in the usual manner. The remedy for this trouble is to use only armoured cables laid direct in the ground and at greater depth than usual if within, say, a distance of 4 ft. from rails.

Pressure Surges.—Resonance, fortunately, is not a very common cause of failure under normal conditions of working. Cables have usually a very heavy factor of safety (between 10 and 20, as a rule) for short periods. For this reason it has been found quite practicable to switch on and off long feeders direct on to the system without using

* On cables jointed in winter these figures will be much exceeded.

any charging devices. Nothing else has ever been done on the large power companies' systems on the North-East coast, which were first put in operation in 1901, and it is therefore somewhat surprising to learn that cable-charging gear was still in use on some other large undertakings as recently as 1904–1905.*

When pressure surges are the cause of breakdowns of cables or of their joints, it is usually the result of a heavy short circuit, which sets up oscillations in the system, and cables may break down due to a rise of pressure at some point often miles away from the short circuit causing the disturbance. There can also be no doubt that the system persists in a condition which may give rise to further pressure rises for some time, as breakdowns often follow upon one another within a few days. Breakdowns on cables caused by pressure surges are usually quite characteristic and easily recognised when an instantaneous protective gear, such as the Merz-Price, is installed. The insulation is generally perforated as if drilled through, or, if the breakdown is in a joint, fine burnt cracks are found through the insulation.

In conclusion, it will be noticed that a large proportion of the breakdowns experienced arise from the use of lead for the outer waterproof sheath of cables. Of all the metals lead is probably the only one which can be conveniently used; but it would be an advantage to use a non-metallic waterproof sheath, if one could be obtained, which retained the great advantages of the present lead sheath without its disadvantages. Hitherto it has not been possible to obtain any such suitable material, and the problem is not an easy one to solve.

Discussion.

Mr. Snell.

Mr. J. F. C. Snell: As there is so little time left this evening for the discussion, I will try and set a good example by keeping to the ten minutes' rule. We have listened to an extremely practical paper, but it so bristles with details which one could take a whole evening to discuss that I must only touch upon the more salient of them. I notice that, so far as the systems themselves are concerned—that is, the solid system or the drawn-in system—we are practically in the same position that we were when this matter was discussed some seven or eight years ago. It may interest you to know that last year when abroad I had to examine a high-tension system which had been laid for some years. The cables were laid in a Howard asphalte trough, and the ground in which the troughing was laid was very full of chemical impurities. The result was that the outside steel surrounding the asphalte had entirely corroded away, but the asphalte itself was just as intact as it was on the day it was laid, and the whole system was in an extremely solid and good condition. I am also reminded by the author's paper of a very bad slip on an embankment that I experienced some five or six years ago. Some 6,600-volt cables, fortunately for us armoured, were laid along the side of a very steep

* *Journal of the Institution of Electrical Engineers*, vol. 36, pp. 85 and 120, 1905.

Mr. Snell.

embankment, supplying an important shipyard in which some 7,000 or 8,000 men were employed. After very heavy rains, followed by a frost and then a thaw, the embankment slipped. These two cables, which were 3-core, 0·1 sq. in., I think, in section, were left supported between abutments 40 yards apart, and they not only held up their stoneware troughing and the bitumen and covers which surrounded them, but also something like 18 in. of clay filling above and a line of paving stones. The weight upon those cables must have been very great indeed, and yet when the whole thing was cleared away there was no sign of any stretching of the cable. If they had been merely lead cables the lead would undoubtedly have drawn and the cables would have broken down. In that case the double-wire armouring undoubtedly saved the cables. May I draw attention to one other practical point which I have come across during the last twelve months? I had occasion to examine some cables which had broken down badly on a railway embankment, and I can verify what the author says, that the continued movement of an embankment caused by the passage of trains—in this case rather heavy freight trains—undoubtedly causes the cable to "work." I suppose what had really happened was that the stoneware trough in which the cables were laid had been disturbed by vibration and had worked at the joints, the bitumen at the joints had been gradually broken away, and then the troughing edges had gradually indented the lead until the lead was broken; possibly the movement of the whole embankment had caused the lead to crystallise and to break through. To get over that we took the precaution to lay armoured cables, with a cushion between the lead sheathing and the armouring, not quite in the same detail that the author describes on page 321 of his paper, but somewhat similar. We laid it in this case in a wood troughing instead of in stoneware. It seems to me there is one important matter in the laying of cables on a solid system that has to be borne in mind, and that is the quality of the bitumen or insulating compound which is used to fill in the spacing between the stoneware or wood troughing and the armouring of the cable or the lead sheathing, as the case may be. With the help of Mr. W. P. Digby, who made a number of experiments in his laboratory, we have been using for some time past a bitumen refined to a certain specification, and it may be of assistance to some of you, and it may also be subject to criticism on the part of some of the cable manufacturers, to tell you what that specification is. I do not know that there is anything very original in it, but it does embody, as far as I can see, all the important details. Of course it has to be softened by the addition of a certain oil, and it must be free from wood and coal-tar pitch, from sulphur compounds and from resin. In other words, you want to get as much as possible a homogeneous compound. We specify that it shall not contain a greater percentage than 35 per cent. of ash, and that its ductility—which is a very important matter—shall be such that at a temperature of 82° F. it shall begin to flow, and that it shall flow freely at a temperature of 100° F. Some considerable experience of

Mr. Snell. that compound has shown us that it is to be trusted. Although a great many people might think it is quite an unimportant detail, I do think that the selection of the bitumen, or, at any rate, of the material which is to surround the cable and protect it for many years, is of the very greatest importance.

There is one last matter to which I will refer, and it is this. The author speaks of the protection of the cables from electrolysis. It is a debatable matter whether or not one should deliberately earth the sheathing of the cable at certain definite points. Although there is much to be said both for and against, I think the better way is deliberately to earth the sheathing of the cable at certain defined points, because then we know what ills we may suffer from, whereas if we do not do that we may fly to other ills we wot not of. I should like to ask the author whether, in the vacuum process for forming his joint, it is not a fact that, with the viscosity of the liquid which he uses to fill the joint-boxes, he does not get air spaces left in the joint-boxes due to the soaking up into the spaces between the conductors and the dielectric which have been left by the process of vacuum extraction—that is, the extraction of the air from the spaces between the dielectric and the conductor. And, lastly, I would ask the author if he can give us two other particulars, namely, the temperature limits of these 20,000-volt cables and the current densities that he is able to work those cores at under emergency conditions. Particulars have been published in the *Proceedings of the American Institution of Electrical Engineers* upon this subject, and I think they have been quoted in Hobart's book, and tables and diagrams have been shown, but nothing that I can see refers to cables working at the higher pressure of 20,000 volts. I believe it is understood that they may be worked up to current densities of something like 1,800 amperes per square inch and yet keep within a reasonable temperature limit. If the author can give us any reliable particulars upon that point he will, I think, add much to the importance of this paper.

Mr. Welbourn. Mr. B. WELBOURN: Speaking as a cable man, I look upon this paper as an excellent corrective to the recent papers we have had on high-tension pole lines. I am very glad to hear the author accept the fact that paper-insulated lead-covered cables are the only practical means of transmitting energy underground nowadays. So far as I know, this is the first time it has ever been declared publicly. The author deals, in two or three brief remarks in his paper, with the expected life of paper-insulated cables, and in one place he mentions that the probable life will be from 20 to 30 years. I would like to ask the author what evidence he has in support of that statement. I have looked into the question very carefully at times but consider there is no supporting evidence. Paper-insulated lead-covered cables have been in use now for 21 years in this country. The copper certainly will not deteriorate, and careful examination of the paper after 20 years' use shows no deterioration, so far as we can tell from microscopical, chemical, and tensile tests. Therefore the

Mr. Welbourn.

question really comes down to the life of the lead pipe. The gentleman who introduced paper-insulated cables into England once told me that lead pipes in good condition had been dug up at Herculaneum. [Mr. HAMMOND: With cables inside them?] No, water-pipes. Of course in England, and in all densely inhabited countries, the conditions underground are different. There may be organic matter present which will attack a lead sheath unless it is properly protected. The author on that point accepts the fact, I think, that wherever we bury a cable underground and do not go in for a drawn-in system, we should lay an armoured cable. I think the author sets that out very clearly in his paper. I am very glad to see this because there are many here to-night who have heard me speak on this subject in private. I have felt strongly for years past that the armoured cable, where it is necessary to bury a cable direct in the earth, is the right solution of the cable problem, because one knows it is very difficult to get a proper solid system in the streets where you have to deal with variable climatic conditions and also with unskilled labour. There have been certain developments recently in the methods used for protecting cables, especially armoured cables, which are not referred to by the author. I think it is now quite correct to claim that one can make in the factory with skilled labour and send out ready for laying, a much better solid system than one can ever make in the streets. I might mention, in confirmation of what I am saying, that the Home Office Committee on the use of Electricity in Mines has just given a very emphatic endorsement to the use of properly armoured cables for underground colliery conditions, where sometimes there are very corrosive waters which would attack the armouring, were it not properly protected. One thing that has militated in this country against the use of armoured cables has been the attitude of the Local Government Board in granting only short-period loans to Municipalities. I think I am right in saying that they grant loans for armoured cables for only 15 years, whereas for the solid-system work they grant them for 25 years. I suggest there is scope here for the Institution, either alone or in conjunction with the I.M.E.A., to educate the Local Government Board. Then the author deals somewhat lengthily with the important question of electrolysis on lead-sheathed cables. Speaking of feeder cables only at the moment, I wish to state as the result of my experience—and state it very emphatically—that a case of electrolysis need never occur. There are, as the author has stated, two schools of thought on this question, and, with Mr. Snell, I most emphatically belong to those who believe in earthing at definite points, and in maintaining the electrical continuity of the lead sheathing. Where we have an armoured cable there is one point that should be borne in mind that is not always realised, and that is that not only should we maintain the continuity of the lead sheathing, but we should also maintain the conductivity of the armouring at its full value, and we should take as careful steps to earth the armouring as the lead. If those simple precautions are taken there is no doubt that the trouble which has been alleged

Mr. Welbourn. would not be experienced. I had intended to deal somewhat at length with the question of earthing, but possibly that is rather outside the scope of this paper. I would say, however, on this earthing question—because it is a very important one indeed—that when the sheathing of a cable system has once been earthed it should not be assumed that it is going to be right for all time. Earthed wires do corrode, and there is also some reason to think that the electrical conditions underground do alter with the opening of electric railways, electric tramways, and so on. I have come across definite cases where earthing has been carried out, years ago, and the recent insertion of an ammeter in the earth wire has shown that not only is the earthing not doing any good, but it is doing harm, because current is leaving the earth and going into the lead sheathing, and, unless the other earths that are on the system are efficient, that is going to lead to trouble. The earthing arrangements need overhauling from time to time.

With regard to the question of jointing, which is an extremely important part of the paper, I think the author has hit on two very good devices in his braided joint and in the expansion joint. The braided joint seems to me to be so self-evidently good that it is hardly necessary to discuss it. I would like to ask the author, however, what was the section of the conductor on which he made the tests mentioned on page 323, which are very striking if the section of the conductor is comparatively small. The expansion joint is a great step forward, and meets a long-felt want among cable engineers. I have no doubt whatever that, on power systems and on heavily loaded mains, these expansion joints will be very extensively used. I expect there are engineers present who will be able to tell us their experience of troubles which could have been overcome by the use of these expansion joints. One that I am acquainted with on a high-tension system was where an open circuit was found. On going to look for the trouble, which was due to subsidence, the cable was found about 10 ft. deep. The cable insulation was perfectly sound, the joints were of the telescoped type, wrapped with copper wire and soldered, and the soldering had fortunately been badly done. The subsidence had pulled the cores apart, the binding wire had unwrapped and maintained the circuit until a transformer at the far end of the line failed; the wire acted as a fuse, and quietly put the cable out of business. It is a very good feature that the author has directed our attention to the jointing of 20,000-volt cables. Up to the present, the results with joints for 11,000 volts have been extremely good. I have made thousands of 11,000-volt joints without having the slightest difficulty. But pressures have now gone up to 20,000 volts and even higher, and possibly one must reconsider one's methods. The author has mentioned 30,000-volt cables, and I am not sure that 40,000-volt alternating current cable is not within the region of possibility, provided the user understands that he is buying a cable that has not the same factor of safety that a 30,000-volt cable or a 20,000-volt cable

has, and provided also he will run it at a fairly low temperature, current density, and frequency. With regard to the question of trouble due to vibration on railways, I have found that a very good rule is to lay the cables 4 ft. deep, 4 ft. away from the nearest rail; and wherever it goes under a track to lay it not less than 6 ft. deep. If that simple rule is followed, I think it may be taken that no trouble will ever result with wire-armoured cables. Mr. Welbourn.

Mr. J. S. HIGHFIELD: The whole of this paper deals with the difficulties of laying cables, jointing them, and using them, and not with difficulties connected with the cables themselves. Mr. Welbourn has said that the difficulties of the cable from the point of view of the design and manufacture are almost negligible. I think it ought to be so, because the cable as it is made to-day is an exceedingly expensive piece of apparatus. I agree with what Mr. Welbourn said as to the advantage, if a solid system must be laid, of making that solid system in the factory and not trying to construct it in the street. In my experience it is an exceedingly difficult thing to lay a solid system in ducts which is absolutely as satisfactory as one would like it to be; and so long as the ground is good and there is not much subsidence, I am inclined to hold that the drawn-in system is not only cheaper, but is also superior. I want to say just a few words on the question of jointing. I speak particularly of concentric cables, because I have not tried the method I intend to mention with 3-core cables, although I have no doubt there would be no difficulty in using it. Some time ago the Metropolitan Company had a certain number of joint failures with 10,000-volt cables—not very many, but still, three or four failures which were rather awkward. That resulted in the engineers who have charge of the mains system investigating the question of joints rather carefully. The joints were first made by tapering the paper over 5 or 6 in., bringing the insulation into a cone form, then winding the joint with tape and sometimes with mica, and building up a layer of insulation rather thicker than the original insulation. On test these joints were found to fail at 30,000 to 40,000 volts alternating at 60 cycles, and the failures in every case occurred through sparking where the tape abutted on to the paper. As a result of that, stepping was tried; that is to say, instead of making a smooth cone, we made 4 or 5 steps in the paper, using the tape again without the mica. The effect of that was to raise the breakdown pressure to something between 50,000 and 60,000 volts. We then tried to make the joints entirely of paper, using no tape. A similar class of paper was used to that with which the cable is insulated. The paper strip was wound carefully on to the stepped insulation, and we found that we could obtain test pressures of about 60,000 volts. The number of steps was then altered, and we finally adopted 5 steps, formed by tearing off the paper, not by cutting. We took the further precaution of winding the impregnated paper on a reel so as to avoid any contact with the jointer's hands. In this way we made a joint quite free from moisture. With this type of joint we obtained pressures up to 84,000 volts alternating without breaking down Mr. Highfield.

Mr Highfield.

the joint. We have had joints insulated in this way stand 130,000 volts alternating for a few minutes. This method makes an extremely inexpensive joint, and I prefer it to any other. Then I would like to say one or two words about the testing of long lines of cables. A long length of cable constructed for 10,000 or 20,000 volts pressure requires a very high charging current. Apart from the fact that a large amount of expensive machinery is necessary for providing this current, I am not at all clear as to the effect of that sort of stress on the cable itself. The cable manufacturers could probably tell us more about it. I have tested cables and joints up to 130,000 volts with alternating current, and have found that when they break down they do not break down through a clean electrical puncture, but owing to the heat which is generated in the joint by the energy lost in the form of dielectric hysteresis. I have tested similar joints in cables with pressures up to 150,000 volts direct current, and no difficulty is experienced. There is no heating, and very little power is taken.

I am decidedly of opinion that much the best method of testing long lengths of cable, even when they are for use with alternating current, is to use a very-high-tension direct current. It is quite easy to obtain a direct-current pressure up to 300,000 volts, and as there is no charging current and only leakage current has to be dealt with, a machine of less than 1 k.w. is capable of testing very long lengths of cable. I have tested about 14 miles of cable with a machine which gives something under ½ k.w., the bulk of the loss being due to discharge through the air. The advantage of using direct current is not only that a much smaller machine can be used, but the pressure can be much more accurately measured, and the electrical stress to which the cable is subjected can be accurately controlled, and, owing to the fact that there is no heating, there is far less risk of damaging the cable when this method of testing is used. Great caution must be exercised, however, in discharging the cable after testing it at these high direct-current pressures as the cable will retain a considerable charge, for several days even, after it has been earthed.

Mr. Patchell.

Mr. W. H. PATCHELL: I should like to ask the author what authority he has for the reference on page 315 to "the copper tape Board of Trade earth sheath." I have always understood that such sheathing was not a Board of Trade compulsory system. The Board of Trade has been blamed for a good many things, but I do not think it is quite right to blame them for that. I believe the arrangement was offered to the Board of Trade by a cable manufacturer and accepted by them. The manufacturer then said it had the Board of Trade blessing and sold it. With regard to the question of burying cables in clay, I have frequently had to cart clay to places where the virgin soil was bad, and we have had no trouble with the cables after that. In colliery districts particularly it is very often advisable to lay the cables in clay, and to be very careful in doing it. The vacuum joints interested me very much. We have been used in the last few years to seeing the Post Office and the National Telephone Company using pressure

blowers for drying out the air cores. I understood that pressure blowers were used because there was a danger of a vacuum drawing moisture into the cable. The author does not appear to fear any danger of drawing water into his joints, and I should like to ask him if he has had any trouble in that direction. It is very nice if we wish to exhaust a joint to be able to do in the street what we are now generally accustomed to doing in the factories by putting the cable into the vacuum tank, carefully exhausting it, and then letting in the impregnating oil, whatever it happens to be, but I thought it was a little risky to try and reproduce that result under street conditions. I quite agree that a great deal of trouble has been caused on cable joints due to the dirty handling of the jointing materials, however good the material. In connection with my paper six years ago* describing the cables in the Bow system, I laid stress on that point, and micanite tubes which were being brought forward at that time to get over a great deal of the difficulty were mentioned. Mr. Highfield has reiterated that point to-night. If the paper or tape is to be put on in the streets it is best to have it on a reel and not to let the jointer handle it more than is absolutely necessary. Mr. Patchell.

Mr. Roger Smith: At the bottom of page 317 the author refers to cables laid solid in asphalt troughing, and invites information as to results obtained. Something that I should have said has been already anticipated by Mr. Snell; but I might perhaps mention an experience with high-tension cables, working at 6,500 volts 3-phase, laid on the Great Western Railway between Park Royal generating station and three sub-stations. These cables partly serve the electrified track between Bishop's Road and Hammersmith and Addison Road for traction purposes, and partly supply power and lighting for Great Western purposes. This is only a small system from the author's point of view, the total route miles being 9½, with 27 miles of high-tension 3-core cable up to the sub-stations, 10 miles beyond sub-stations and 14 miles of low-tension concentric cables, making about 51 miles altogether. After full consideration Howard asphalt troughing, laid on a 4-in. bed of concrete, was provided for all the cables enumerated above and in addition for a multicore telephone cable. The high-tension 3-core cables were paper-insulated, lead-covered and wire-armoured, while the low-tension cables were only lead-covered. The reasons for choosing this system of laying were very much those set forth in the paper, namely, the avoidance of the use of bridges in the troughs, as advocated on page 318 (although small asphalt bridges were used to ensure the bitumen getting under the cable), and secondly, as mentioned on page 331, in order to insulate the lead sheath from earth so as to prevent electrolysis. Both the lead sheath and the armouring of each cable are connected to earth at the end terminal boxes in generating and sub-stations and at the intermediate terminal boxes in two large disconnecting chambers along the route. A third reason for the choice of a plastic troughing was to counteract vibration. It may here be Mr. Smith.

* *Proceedings of the Institution of Electrical Engineers*, vol. 36, p. 153, 1906.

Mr. Smith. pointed out that the description of Howard asphalt troughing on page 318 is not quite correct. It is not a steel trough lined with asphalt, but an asphalt trough protected during handling and laying by an outer trough of thin sheet-steel which serves very much the same purpose as the centreing of an arch, and is not necessary for the strength or stability of the troughing after it is once laid. The principle of this troughing is that the cable should as nearly as possible fit it, that Trinidad bitumen should be used just to cover the cable and that the rest of the filling should be a much cheaper asphalt concrete.

At a test made yesterday (March 8th) on the only length of cable that is available, some 300 yards of route which has been out of service for three or four years, it was found that the resistance between the sheath and earth through the Howard troughing was 2,000 ohms, which, of course, would be sufficient to prevent any electrolysis by stray currents. The joints are of the type shown in Fig. 12, with the exception that as the finished joint has to fit into the troughing all the cores are brought out one over the other in one vertical plane. The lead sheath enclosing the joint, filled in with fluid compound, is a good deal higher than the rest of the level of the troughing, and is simply covered over by a piece of inverted trough. The joints in each core are of the ferrule type, insulated with loose pieces of mica and paper alternately, and then each joint and the whole taped over. I should like to point out that the fact that each core, or rather the two upper cores, are slightly looped upwards at each joint might, if exaggerated, form a useful expansion joint very much in the same way that a steam-pipe bend makes an expansion joint. As far as I know, the method of laying 3-core cables solid in troughing is the only one which demands a joint of practically the same width as the cable itself, since where many cables are laid side by side each joint must fit into the troughing. This joint has the great advantage of the same continuous support from the troughing which the rest of the cable receives. In railway work, where the width of a cable trench is restricted, the fact that very satisfactory joints can be made in a manner which keeps the over-all width occupied in the trench exactly the same throughout may be a matter of very serious importance. This is particularly the case where cables have for any reason to be laid in long culverts necessitating cable joints in the culverts, but more especially where, after cables have been laid on the boundary of the railway, that boundary is afterwards extended and a culvert has to be built over the cables, which is, as a rule, far cheaper than taking up and relaying the cables. These cables, which were all laid by Messrs. Siemens five years ago, have given absolutely no trouble. They have never yet, however, been overloaded in the manner suggested in the paper. There are 600 joints, only one of which failed during the contractor's period of maintenance, and not one of them has failed since. The cables cross under the lines twenty-seven times—in some cases under the whole of the main lines going out of Paddington, while for a good part of their length they are laid in

Mr. Smith.

the 6-ft. way on the top of brick arching, the troughing resting just on the crown of the arches. In that part of the route there are nine bridges along which the cables are laid, and between the end of the concrete bed in the trench and the bridge structure they are laid up a sloped steel plate about 10 ft. long, fixed to the edge of the bridge and anchored into the concrete with a space beyond the anchor left free for bending. This flexible support was intended to distribute and damp down the effects of vibration, and it has been perfectly successful, no failure of any sort having occurred on these slopes. The only trouble that has happened on bridges is that in the middle of the span of some of them the cable troughs have splayed out sideways both sides of the centre line. Whether this is due to expansion from heat, or whether it is due to an effect of vibration with nodes at the ends of the bridges and the maximum amplitude at the centre of the span, I do not know, but it has caused no inconvenience. All high-tension cables were twice tested at the maker's works during manufacture to 20,000 volts, once in water before sheathing and once dry after sheathing. After laying, every length of cable was tested to 12,000 volts alternating for 15 minutes, and it is interesting as showing what careful supervision and good workmanship in the way of jointing can accomplish, that no length of cable broke down under the tests on site. I thought it might be of interest to mention the cost of maintenance within the last four years that this small system, all laid on one method, and working at 6,500 volts, has entailed. For one year the cables were under the contractor's maintenance. In 1907 the maintenance of the 37 miles of high-tension feeder cables only cost £9; in 1908 it cost £30, largely due to the purchase of a tar boiler; in 1909 it cost £17; and in 1910 £18 10s. The average per annum for the 37 miles is £18 12s. For the whole 51 miles the average has been £41, of which by far the greatest proportion is for the telephone cables. One inspector divides his time between the maintenance of the 50 miles of cable and 10 miles of single track electrified with positive and negative conductor rails. For the latter maintenance, where jumper cable connections bridging gaps in the conductor rails have frequently to be altered, he has the assistance of a jointer, but the time which he can spare from patrolling and inspecting the electrified track is sufficient for the maintenance of the whole of the cables outside buildings. A good deal has been said about the difficulty and cost of laying cables solid, but I think that a system which has never failed in 5 years and has cost less than one-tenth of 1 per cent. of its capital cost for annual maintenance proves that the difficulties can be overcome and that the expenditure is justified.

Mr. Mordey.

Mr. W. M. Mordey: The author, in referring to the question of external damage, expanded what is said at page 320 in the paper about the leakage of steam and hot water causing cable breakdowns. I understood him to add that he found cables in hot places very liable to break down, and that he wondered why. I suggest that it may be simply because the resistance of dielectrics goes down very consider-

Mr. Mordey. ably with rise of temperature, and that therefore a cable will break down at a lower voltage if the temperature is raised. I should expect a rise of no more than 50° or 60° C. would cause a very serious drop in the insulation.

Mr. Howell. Mr. A. HOWELL: There are one or two points I would like to direct attention to, first of all with regard to the solid system. The author points out that it is a very expensive system. I think the reason for that is that concrete is proposed. I do not think, with the many excellent forms of ducts or conduits that are now on the market, it is essential to use concrete. We all know that concrete is very expensive when put down in such large quantities and when it has to be laid over any great distance. If the use of concrete is adopted in order to give an extra wall between the various ways to protect the other cables against a faulty one, I think the makers would be prepared to thicken up the walls, which are now about ⅝ in. to 1 in. for a much less cost. With regard to manholes, these are always a necessary evil. I venture to suggest that, if they were drained to sewers—which, of course, would have to be surface sewers—and there were many of them, it would be rather an expensive matter. I do not think much draining could be done for less than about £8 or £9 per manhole. I should also like to refer to Figs. 3 and 4 given by the author in connection with the solid system. I notice there that he shows a very robust tile. I should like to ask him whether he has any experience with a tile having a top in the form of a watershed. I think such a tile would give a better resistance than those shown, particularly when a crowbar is driven down upon it. Furthermore, there is a distinct advantage in arranging for a longitudinal channel in the tile, as it permits of the pitch at all times flowing very readily, ensuring the filling of the trough. While on this point I would like to mention that a lot of trouble in the solid system is due to the men trying to fill too great a length at a time. If it was filled in in short lengths, with a tile removed for inspection at, say, 9, 10, or 12 ft. distances, I think there would not be a great deal of difficulty in getting the trough full if proper pitch plugs were used at the ends of the lengths to prevent the pitch going away. The author also goes very fully into the question of armoured cables. Sometimes when one lays armoured cables as a solid system it provokes a great deal of ridicule. The armoured cable is generally looked upon as being a cable which is made to lie direct in the ground; but there are many engineers who will bear me out when I say that an armoured cable laid in a soil of inferior quality or of a chemical nature, or containing other doubtful ingredients, is not the right type of cable to lay. No one would agree to laying armoured cables in a water-logged district, because there is bound to come a time when the outer jute surface will be soaked through; and since the trench becomes a drain for some one else's trench which has been previously opened, it is a very moot point as to whether the armouring of the cable will not come to grief. I think in many instances engineers have laid armoured cables solid for the purpose of gaining advantage from the point of view of handling the cable. In laying an

extensive system of lead-covered cables, if it is to be done properly it requires a great deal of care in actually handling the cable. It is the usual thing, for instance, to see a navvy with great hob-nailed boots walking along the cable when the ganger's back is turned, and there have been some very nasty blows given to cables in that way which have afterwards caused trouble, the reason of which has been difficult to ascertain. There is an advantage in laying armoured cables solid, because we get the benefit of quicker methods of laying the cables; also considerably longer lengths can be laid, and there are in addition all the advantages of the solid system. With regard to the question of joints, I was very pleased to see the author go so fully into that question. From the diagrams he has given and the samples he has shown I think he has brought to light some extremely useful ideas. There are many joints, particularly on the low-tension side (which joints are far more numerous than transmission cable joints), in which I have found from experience that the conductivity of the joints put forward has not been much more than one-tenth of the conductivity of the cable that would occupy the space were there no joints there. If the question of conductivity in jointing is not looked after there will be a considerable increase in the equivalent lengths of the cable where these joints are to be found. There is at the present time a craze for a cheap joint; but I think the time will come when that will be regretted. I think the conductivity of the joint, no matter what system is used, should be at least equal to the conductivity of the cable that would occupy the space were it not there, and certainly it should be within 1 or 2 per cent. of this. **Mr. Howell.**

Communicated: From the author's reply to my remarks concerning the pitching-in of cables on the "solid system," I am afraid that I did not make my meaning sufficiently clear; for of course it would be out of the question to attempt to fill in troughs at such short distances as those to which he understood me to refer. I may say that instances have come under my notice, in which cables have been put down on the solid system, where yards and yards of troughing have never seen but the smallest trace of pitch filling. In such cases only one method could have been used, *i.e.*, putting tiles on long lengths of troughing already containing the cable, filling the earth over, and trusting to the pitch to run in and fill up solid when poured in at one end. This method can still be seen in operation at times. If the troughs are placed in position, their sides packed with earth and the cable laid in, the tiles may be put on in place, leaving one out at, say, every 3 yards for inspection of the pitch, the troughing can be rapidly and certainly filled, the inspection tiles being then put back as the pitch rises, and the earth rammed back. I agree entirely with the author as regards the shrinkage of black compounds in joint boxes or sleeves. This shrinkage is usually understood to take the form of an even surface shrinkage, but for a joint box closed at the top and filled through plug-holes that is not so, and the author's description is the true one. In a proper watertight box or sleeve viscous compound is the safest thing to use, unless

Mr. Howell. black compounds can be got to fill up the spaces as effectively as the former one.

Mr. Trotter. Mr. A. P. TROTTER: The author speaks of two methods of avoiding electrolysis; in the first place, he speaks of earthing the lead sheath at frequent intervals. I am one of those who believe that is wrong. I believe, as two speakers have mentioned, that it should be earthed at certain points. There is no mystery as to where those points are. They should be at the most negative points upon the cable. I am assuming there is a tramway, railway, or very leaky continuous-current supply system in the neighbourhood, otherwise there is no necessity to earth; but if there is a tramway the most negative point or points, such as boosted return feeder points should be found, and earthing should be effected there. If any current has got into the cable it should be let out through a bond. Earthing at frequent points is only tempting the current to get in at other points.

With regard to the question of the protection of the cables, the author speaks of different methods of protection. It appears that the majority of engineers nowadays are adopting the system of protecting cables laid solid in the earth with a creosoted plank 2 in. thick, as wide as may be, in 12-ft. lengths; because if a conscientious navvy with a pick is told to make a hole in the ground he will go through almost anything he can find. But what does trouble him is a 2-in. plank 12 ft. long. He has no suitable tools for cutting it, he finds he cannot shift a whole plank, but he can toss tiles out of his way. It is also a very valuable warning to him. Armoured cable laid direct in the ground seems to be one of the best methods of laying important cables. Other methods may be more suitable for distribution cables, low-pressure cables, and other purposes. The life of an armoured cable is a question of the soil. I hesitated at one time about burying armoured cables in the ground, and I asked an engineer who proposed to lay rather an important cable in that way what his soil was like. He sent me about 10 in. of an armoured cable that had been ten years in the ground on which the whitewash was still visible on the outside. In some soils it is perfectly safe, in other soils it may be necessary to have a certain amount of protection on the outside. In general, I consider that for an important main an armoured cable laid in the ground with a 2-in. creosoted plank on the top of it is about the best way of laying it.

Mr. Beaver. Mr. C. BEAVER (*communicated*): I am much interested in the results the author has obtained with his expansion joint-box, but should like to ask whether the breakdowns on cables, apart from the joints, which he states to have been frequent prior to the introduction of his box, were not invariably *near* joints, *i.e.*, where a part of the cable which was free to move was in close proximity to another part in which the movement was limited or restricted. This has always been my experience, and in fact it is difficult to see how the expansion joint can affect or relieve any stresses set up by expansion and contraction of the cable except in its immediate vicinity. The joint is not the seat of the heating, and the breaking of the joint is due to the movement of a

Mr. Beaver.

certain length of cable on each side of it. In other words, it is not so much a matter of the relative movement of conductors and box, as of the bodily movement of the cable outside the box. The preventive measures I have hitherto found successful have been to provide a loop of cable in the manhole on each side of the joint-box, so that the box only formed an integral part of the expansion piece. In bad cases, and where space was limited, joints made with tail-end boxes connected across by loops of rubber cable, and free to move on shelves or rails, have been found successful. Such methods are, of course, cumbersome as compared with the author's method, and for this reason I am anxious to hear as to what happens to the cable sheaths in the vicinity of the box. Lead sheaths in particular are easy to expand, but if deformed in the least by such expansion will take a permanent set which will be exaggerated by each successive expansion, and soon become fractured. With regard to the filling of joint-boxes and the author's preference for an oily or viscous compound, it is obvious that compounds of this character will be necessary for joints in which expansion arrangements are provided. For ordinary work there is much to be said in favour of solid compound with fairly high melting-point. With such compound all questions of leakage, which, by the way, are not inconsiderable where cables are run at high current densities, are swept away. On the other hand, it is more difficult to ensure perfect filling of all interstices in the joint and the box. These difficulties are not, however, by any means insuperable. Some time ago I made a wide series of experiments on this box-filling question, including vacuum and pressure methods of filling. As a result of these experiments, I came to the conclusion that the simplest and most certain method was to introduce the compound into the box by means of a funnel screwed into a plug-hole at the highest point of the box. The only precautions thereafter to be observed are that a head of compound is maintained in the funnel at a higher temperature than the compound which is cooling down in the box, and that this condition should be maintained until the compound in the box has cooled down to somewhere near its solidifying point. The action briefly is, that the entrapped air and gas bubbles occluded in the compound escape *viâ* the funnel, and their place is taken by compound from the funnel. The physical contraction of the compound in the box due to cooling is also compensated for by drawing compound down from the funnel. In this way the boxes can be absolutely and with certainty filled with a compound having such a melting-point that working temperatures do not displace it in any way.

I should like to say a word on the subject of bridges and the author's preference for glazed earthenware. I prefer unglazed earthenware bridges, because they can easily be obtained of such a quality that they do not depend on glazing for moisture-resisting properties, and the matt surface helps the adhesion of the trough-filling compound. With regard to asphalt bridges and the idea that they become crushed out of shape by the weight of the cables, I may

Mr. Beaver. say that I have not only kept cables under observation which have been laid on asphalt bridges, but I have experimentally exaggerated the worst conditions by laying steel bars in imitation of cables so as to get not only a great weight per length, but a great concentration of weight owing to small diameter of the steel bar as compared to that of a cable of equal weight per length. I have found no perceptible crushing of the bridges up to a weight of about 8½ lbs. per bridge. These bridges certainly soften to some extent when the hot filling compound is poured over them, so that possibly any pressing down which the cables receive may be responsible for the idea that the weight of the cable crushes them. They are, of course, much more easily broken in handling than porcelain bridges. I agree with the author that wood bridges should never be used, but I would add that my experience as regards their supposed attack on the lead sheathing of cables is that it is more often a matter of the wood bridge forming an electrolytic path than of simple chemical action due to the products of decay of the wood. With regard to armoured cables laid direct, I quite confirm the author's remarks as to the favourable results as regards preservation in the case of dry, sandy soils. I recently examined some rubber insulated cables which had been laying in sandy soil for the past fifteen years, the steel tape armouring of which was not even tarnished. A layer of well-punned clay is, as the author states, a decided protection to cables in bad soil. With regard to the improved coverings which the author describes as now being used by the North-East Coast power companies, I should like to mention that my firm made lead-covered cables with a coating of vulcanised bitumen over the lead about thirteen years ago for one of our largest railway companies, the object being to afford the lead special chemical protection on account of it being laid in the track ballast. For several years past the Glasgow Corporation have had a certain type of cable sheathed with vulcanised bitumen over a lead covering, and then a second lead covering applied over all. I quite agree with the author that the slight extra expense entailed by special preventive measures of the kind described constitute a good investment.

The laying of cables in chalk or limestone is not a condition commonly met with, but as a matter of interest while on the subject of soils, I would mention that I have found calcium carbide formed as the result of a cable breakdown where a comparatively large arc had occurred. The limestone and the carbonaceous matter from the filling of the cable trough, together with the arc, provided all the conditions necessary for the formation of the carbide, which, of course, when wetted gave off acetylene quite freely. Touching on the question of electrolysis, there is no doubt that continuous bonding and judicious earthing of metallic sheaths is a much more definite and controllable method than the alternative of insulating the lead sheath. Unless we treat the lead sheath as a live conductor, and see that it is insulated accordingly, we are always faced with the possibility that a local failure of its protective covering, whatever it may be, may lead to

leakage current passing *viâ* a limited area. As this entails a high-current density, the consequent local corrosion which may ensue will be very severe, so that failure will be likely to occur before there is a chance of discovering it. No conduit into which water may leak, much less one which will absorb water, can be regarded as a preventive against electrolytic corrosion. Mr. Beaver.

Discussion before the Newcastle Local Section on March 6 and 20, 1911.

Mr. H. G. A. Stedman: I trust Mr. Vernier will not mind enlightening us on one or two points, viz.: No mention is made in the paper of the problems involved in running transmission cables across rivers, docks, etc., as often has to be done. What form of protection for the cables would he recommend, also how long a life should such cables have? A difference of potential frequently exists between the lead sheath of well-earthed cables and the rails of railway lines in the vicinity. What is the explanation of this? Is it likely to cause trouble—the polarity reverses at times? With regard to the vibration troubles, if the author has any samples of faults produced by this I should like to see them. On page 315 it is stated that a covering of tape and braid is a protection against chemical action and electrolysis when applied to the plain lead-covered cables. From experiments made with short lengths of cable it would appear that moisture would be absorbed and held by this covering, and thus its protective properties become negligible. This is borne out by the statements on page 331. What is the best method of distinguishing between Trinidad bitumen and pitch blended with oil? What is the best proportion of the latter to use to give the most durable results as to flexibility? Mr. Stedman.

Mr. C. S. Vesey Brown: I should like to ask one or two questions. First, with regard to the question of switching on 19 miles of cable without any charging device, I may say this is totally opposed to what I may call first principles. There must be something more in connection with this which Mr. Vernier has not mentioned, and I, at least, would not like to switch on high-tension cables for such a distance at anything like 20,000 volts, or even at 5,000 volts. If a cable could be subjected to that treatment without the provision of charging devices to withstand the resultant high pressure it is quite new to me. Would it not be better to provide simple charging devices at a moderate cost with a resulting reduction in the cost of insulation and the knowledge that one had a more certain provision against the risks involved? I am interested to hear of the way in which Mr. Vernier has dealt with the trouble due to the expansion of cables, and, although it appears to be a satisfactory one, I would like to know more about the creeping effect of the tube upon the conductors shown in Fig. 17. Unless these are thoroughly protected from creeping they will undoubtedly tend to buckle the ends of the conductor. Perhaps Mr. Vernier will give some idea of the relative proportions of the tube, braid, and conductor. I Mr. Brown.

Mr. Brown. would further like to know whether the design shown has been worked out by "rule of thumb" or according to a basis of mechanical strength. Regarding the question of the oil syphoning out of the joint, if I remember rightly this had been put down to the alternate expansion and contraction of the cores; but that is new to me, as I have always understood that it is entirely due to a capillary effect of the core insulation. The drying-up of the insulating material inside the cable gives a vacuum which, with the assistance of air leakages along the cores, all help the capillary action. The drying-up of the joint-box insulation is one of the most serious items of underground cable systems. It has generally been held by outsiders that the installation and maintenance of a cable system is a very simple matter, but we know that a cable system requires to be more carefully engineered than even the power house. I remember one of the members of this Institution, who was here many years ago, engineered a cable system in this district (South Shields), perhaps more thoroughly than was necessary, but I believe the greater part of that system is as good to-day as when it was installed. Considerably more time and money was spent on it relatively than the rest of the plant, but the result is undoubtedly in favour of the view that the time and money has been well spent. The present-day practice seems to be to get there as quickly as possible in order to get the customer connected up without thinking of the future maintenance of the cable and system generally.

Mr. Robb. Mr. J. M. ROBB: I have been much interested in Mr. Vernier's remarks regarding subsidences. The most difficult analogous case in the experience of the Post Office is perhaps that of damage to the cable on the Forth Bridge, and in that case there was a variation in length of 5 in. in twelve hours. This was fatal to the first cable, which did not last long. It was replaced by a 76-wire cable in which 8 bights were arranged vertically alongside the fittings of the bridge to take up the movements. For telegraph and telephone cables the Post Office uses the draw-in system exclusively, and the latest example in this part of the country is the completion of the cable between Newcastle and Leeds, which links up Newcastle with London.

I may mention two points of interest in connection with the drawing in of these cables—the use of petroleum jelly in the proportion of about 1 cwt. to a mile of cable. It not only acts as a lubricant, but is claimed to be a protection against electrolysis and chemical action. There is also the use of a petrol-driven motor winch by which five lengths, each of 176 yards, were drawn in daily; whereas the previous record using hand winches was three lengths. The bonding is very important; we go in for it wholesale, and I consider it to be the salvation of our system.

Mr. Sloan. Mr. R. P. SLOAN: On page 333 Mr. Vernier mentions that the movement per mile of cable may amount to 4 ft. 6 in., and I would like to ask if this is taken into account in fixing the position of the cores when cables are being laid in frosty weather in view of the possibility of the cable expanding as the temperature rises,

Mr. Turnbull.

Mr. C. TURNBULL: I have had some cables laid many years ago with bitumen compound, which seemed very good stuff. Owing to shrinkage in cooling, it went into holes which let water into the joints. Since then viscous compound has been used, and it has been satisfactory. The question of bonding is of perennial interest. I have been content to bond all lead and earth at the station, but this is on a small system only. To earth at other points seems to invite traction currents to enter the lead, especially if the current can by these means get a short cut to the station. Bonding to the water pipes lays one open to claims from the water companies in case of electrolysis. Wood troughing does not appear to be satisfactory, and will probably soon go out of use. Pitch run into troughing on the solid system has sometimes caused trouble when laid down a steep hill, as the pitch slowly creeps downwards and flows out at the bottom. The action may take many years to complete itself, but it seems none the less certain to happen in the end. Has Mr. Vernier had trouble of this kind? The compounding of armoured cables is very important, but it is very difficult to get cable makers to recognise this. Many times cable makers have promised to have the whole mass thoroughly impregnated with compound from the lead to the outer serving, but when the cable has come to hand, this has not been carried out. Makers are, however, gradually improving in this respect. The filling-in of the conductor strands with suitable compound is important as it prevents damage from water creeping along a broken cable.

Mr. Hunt.

Mr. F. O. HUNT: Referring to the figure for current densities on page 323. I would like to ask if this refers to the current density in the joint or in the cores of the cable. In respect to the specially braided joints and the soldering thereof, I would like to know whether these are soldered with any of the fluxes which are very largely advertised, or simply with pure resin, and whether these fluxes are really as free from corrosive action as they are advertised to be. I have experienced difficulty in managing to prevent workmen from using fluxes which are liable to set up corrosion. With regard to vermin eating the lead pipes, I think that they do this simply because they want to get at something at the other side. I remember a case in which it was very obvious that the rats wished to get at something on the other side of a gas pipe, and their destructive capabilities caused a leak of gas which in turn nearly caused an explosion. With regard to the breakdown of cables following surges some time after the surge has occurred, I would like to know whether it is not probably the case that a succession of surges produces cumulative damage which in time results in the breakdown on a comparatively small surge. In the case of the switching-in of long cables, opinions differ as to whether it is safe or not. Probably it would be well to test the voltage effects with an oscillograph, and if this revealed nothing serious, there would seem to be no need for charging devices. The factor of safety for cables was given by Mr. Vernier as 10 to 20. This would mean that Mr. Vernier's cables would stand from 200,000 to 400,000 volts, at any rate for an instant. This seems to be a very high figure,

Mr. Johnson.

Mr. T. B. JOHNSON: In reference to Fig. 2 on page 315, I would like to point out that where the number of cables is small it is better to lead the pipes in and out at the side of the manhole than in the middle of it. The cables can thus be run straight, instead of being spread out at each side as shown in the diagram. Space is provided for working at the cables or for making Y joints, and the cables are readily supported on the side of the manhole. With regard to the question of draining manholes to sewers, I would suggest that in all cases where this is not done a sump hole should be provided. This is readily obtained by sinking a 2-ft. length of 9-in. earthenware pipe, so that the top edge of the socket is level with the floor of the manhole. The bottom of this pipe should be filled to a depth of 6 in. with concrete, with a top layer of cement mortar 1½ in. thick. In boxes and manholes where trouble is experienced owing to street-cleansing operations (or heavy rains), we have found it advantageous to caulk the covers tightly into the frames with tarred yarn and a mixture of crane grease and whiting. Mr. Vernier seems to think that bitumen is quite satisfactory for the solid system, but some years ago Mr. James Perry pointed out that bitumen does not adhere to lead, and tends to crack under vibration, thus forming a path for air and moisture. He suggested that it was advantageous to lay cables in sand moistened with coal-tar, which presses firmly about the lead, thus excluding air and moisture. I should like to hear whether Mr. Vernier has had any experience with this method.

Mr. Vernier refers to armoured cables. Our experience with these was very unhappy. Cables with double steel ribbon were tried, but as soon as cross-roads and streets began to be formed, these cables suffered from subsidences, and the results were disastrous. The insulation could not be kept up, and we now use the draw-in system, even along country roads.

Mr. Morton.

Mr. W. R. MORTON: Referring to the statement on page 315 that taped and braided lead-covered cables should be used for draw-in work on the ground that protection from electrolysis is afforded, this might delay electrolytic action, but given right conditions—*i.e.*, wet ducts and leakage currents—the ultimate condition will probably be worse than with plain lead-covered. These fibrous coverings eventually become soaked with water, so that the cable is continuously surrounded by a sort of wet blanket, which prevents anything in the way of a flow of water, and is calculated to retain in place any deleterious chemicals. In addition they are extremely difficult to pull out after a few years' service, as the compound with which the braids are served sticks to the conduit. I remember actually breaking the conductor of a 37/15 jute-served cable that had been laid for about two years in vain endeavours to pull it out. With regard to asphalt troughing, I have laid a good deal of this. Its chief disadvantage is not in its qualities so much as its price, which, even when care is taken not to waste the filling materials, is a few per cent. above the cost of wood troughing. It gives a structure which is homogeneous and continuous, the joints

being welded. It is also slightly flexible, and for this reason suitable for such positions as are subject to vibrations. It was used, I believe, for the trunk feeders of one of the electrified railways in London (G.W.R.). In addition it runs very much cooler than either wood troughing, earthenware troughing, or cables drawn in pipes, an important point where cables are run at a high-current density. Ordinary armoured cable laid direct runs a few degrees cooler, though probably the bitumen sheath used by Mr. Vernier over the lead on his armoured cable would nullify this difference. With regard to the expansion of conductors due to heat, I believe Mr. Harold Gray, of Accrington, introduced and used with success a device to take care of this expansion. It simply consists in leaving out one or more of the strands in each layer so that room is afforded for the individual wires to move transversely. On expansion occurring, each wire instead of thrusting itself out at the far end takes a slightly wavy form about its own axis, the expansion thus being taken up without lengthening the cable as a whole. Of course, this is no use as a protection against subsidence. I have seen several arrangements designed to cope with expansion and subsidence, but I think Mr. Vernier's is the only one that is both simple and effective. With reference to joint-box compounds, these all possess a high coefficient of expansion, and this not only accounts for the difficulty in filling boxes, but probably accounts for many a case of what is usually called leakage. A cable running warm causes this compound to expand if this is possible, and probably the absorption of oil mentioned by Mr. Vernier is due to this, rather than to leakage or absorption up the cores, any air present in the cores taking the place in the box of the excluded oil when the cable cools down. I should like to hear from Mr. Vernier about his fault-finding experiences. I imagine the "Merz-Price" protection must help him a good deal by providing "clean" faults. A fault on a cable carrying a large power generally results in about half a yard of cable being reduced to a mass of melted copper, lead, iron, and carbon, this throws out of truth the usual fall of potential methods of location. If I am right, it must be a great boon to the mains engineer. On the other hand, it may be that it cuts out a cable which is leaking, say due to damp paper, from one phase before an actual breakdown has occurred, in which case a high-resistance fault has to be found. Again, referring to the use of braided lead-covered cable for solid work with the object of making the filling compound adhere more closely, it is my experience that compound adheres no better to damp braidings than to damp lead. As a braiding, no matter how well served, is bound to take up and retain more moisture on exposure to rain than a plain lead-covered cable, which dries quickly, it appears to me that the risk of trouble is even greater than with a plain lead-covered cable. I would like to mention a form of steel-tape armouring lately introduced, which consists of rolling an arch-shaped rib in the middle of the inner strip. This ensures that the two tapes are maintained in correct position, the one covering the joint, and, of course, strengthening by reason of the shape of the rib the portion left unprotected by the outer strip. Mr. Morton.

Mr. Morton.

I entirely agree with Mr. Vernier that to attempt to insulate the lead sheath from earth as a preventative of electrolysis is not likely to be successful. My own experience is that discriminate as distinguished from indiscriminate earthing of the lead sheath—which, of course, must be electrically continuous—is the best thing. The danger-points on tramway systems can usually be located—such as the neighbourhood of negative feeding-points and cable runs that may short circuit the rail return path—and the connecting of the sheaths to efficient earth-plates at such points helps a good deal. Referring to the value of a bitumen sheath as a protection against electrolysis, mentioned at the bottom of page 321, this will undoubtedly delay the commencement of electrolytic action, but cannot be regarded as an absolute preventative. The fibrous coverings of this sheath themselves become in wet ground a vehicle for electrolysis. The result is that alkalies are set free on the surface of the bitumen sheath. These alkalies attack the bitumen and rapidly penetrate it. The appearance of bitumen which has been so attacked is very similar to a lead sheath corroded by electrolysis. If bitumen were not subject to this effect, it would probably provide the ideal sheath asked for in the last paragraph of the paper, as its mechanical weakness could be allowed for by providing suitable external coverings. I also would like to correct a misunderstanding with reference to the sheet iron formerly used with asphalt troughing. This is merely a former and is used simply as such; it is expected to corrode away, and is in no sense a support for the trough. It is interesting to note that a cable laid in asphalt trough without this iron sheet runs cooler than when the sheath is in place. This is probably due to the fact that a film of air is enclosed between the asphalt and the iron. With reference to the stresses set up in a cable by subsidence, I would like to ask Mr. Vernier if he does not think that the spiral steel strip armour he had adopted is partially, if not wholly, responsible for the freedom from trouble that these cables have experienced. G.I. steel strip has a breaking stress of about 30 tons per square inch, and the cross-section on a cable of the size used would be probably between 1 sq. in. and 1½ sq. in., so that before any strain can have any effect on the insulation or the copper, the armour must either stretch or break down. These cables are only buried 2 ft. deep, and it seems to be extremely unlikely that a subsidence will give rise to such a stress. It is more likely that the cable will cut through the filled-in earth and so relieve the stress.

Mr. Hunter.

Mr. P. V. HUNTER: To my mind the most important statements of fact in Mr. Vernier's paper are, that the mains system represents approximately 50 per cent. of the capital expenditure of an undertaking, and that mistakes are costly. These statements settle the whole policy of the design of laying and maintenance of transmission cables, and properly considered will lead to a conservative policy in which nothing is left to chance. During the last five or six years I have had an opportunity of discussing with Mr. Vernier the various troubles and defects as they have arisen, and the methods of over-

Mr. Hunter.

coming them, and it is perhaps not surprising that there is very little, if anything, in his paper to which I take exception; in fact, in one or two matters I feel inclined to go further than he does. Undoubtedly the most important issue raised by Mr. Vernier's paper is the abandonment of the solid system for cables with improved armouring. In so far as Mr. Vernier's paper is concerned the life of a high-tension cable depends entirely on the effectiveness of the surroundings of the lead sheath in preserving it intact. Turning to page 329 of the paper, it will be noted that there are seven general causes of breakdown. So far as external damage and pressure surges are concerned, the solid and armoured systems may be considered as equal. For resisting chemical action, electrolysis, subsidences, overrunning and vibration, it is considered that probably armoured cables have a decided advantage over the solid system. In the case of subsidences and vibration this will, I think, be readily conceded, and it is undoubtedly a fact that an armoured cable when compared with a similar cable laid solid has a much smaller temperature rise for a similar load, and will thus allow of more overrunning. There remain to be considered chemical action and electrolysis; it is for these troubles that the special bitumen compound sheath over the lead is used. The jute coverings ordinarily used on armoured cables offer very little protection against either chemical action or electrolysis as they absorb water very readily, and as Mr. Vernier mentions on page 321, it is probably for this reason that armoured cables were largely abandoned for the solid system in this country. The sheath of bitumen compound used under the jute is therefore relied on for the prevention of electrolysis and chemical action. As it will not absorb the heavy bitumen compound used to protect the cables, there would seem to be no object in using jute in the construction of armoured cables at all, and for some time the proposal of dropping the jute has been seriously considered. The alternative construction which will probably be generally adopted for work in this district is as follows. The lead of the cable will be coated with a sheath of bitumen or compound as before, and afterwards taped over with two tapes previously treated with the compound. A second layer of bitumen compound will be then applied and the armouring wires wound on. After this a further layer of compound will be applied and two more tapes, the cable will then be finished with a last layer of compound and lime-washed. The effectiveness of such a cable, of course, depends entirely upon the bitumen compound, and this should be just plastic at ordinary temperatures. If an examination is made of the coverings of a cable made in this manner, it will be found practically impossible to remove them, the whole being cemented together by the compound in a very tenacious and solid manner. Another important point is that with a covering of this description, while the lead sheath has a maximum protection, the armouring is also protected by compound.

Mr. Vernier mentions on page 334 of the paper that all cables of the system are switched "off" and "on" without any charging devices.

Mr. Hunter. The reason for this is that none have been found necessary. In reference to Mr. Vesey Brown's point I would say that a more expensive construction of cable has certainly not been adopted on account of this switching. One point to remember in this connection, of course, is that the system is supplied exclusively by a turbine-driven plant and the voltage wave approximates very closely to a sine curve. Under these conditions mathematicians appear to agree that a surge on switching-in will not exceed twice the normal pressure. Another point is that the higher the working voltage of the cable the lower the capacity per mile. In case it may be of interest, I mention the figures for inductive capacity for 1,000 yards measured between one core and the other two and lead sheath for 0·1 sq. in. 3-core cable constructed for various voltages:—

3,000 volts	...	0·28	microfarads for	1,000 yards.
6,000 "	...	0·22	"	" "
12,000 "	...	0·18	"	" "
20,000 "	...	0·13	"	" "

The figures are taken from a cable contract with Messrs. Callenders, and may be regarded as typical. An explanation that cables will stand enormous pressures momentarily will, I think, be readily understood when the fact is thoroughly grasped that the breakdown of insulation is largely a question of heating of the dielectric. An ordinarily constructed 20,000-volt cable will not break down at 100,000 volts (with the working periodicity) for some time. The ultimate breakdown is due to the temperature of the dielectric gradually rising, by reason of the losses in the dielectric, until the temperature reaches a point at which the dielectric becomes a conductor and breaks down. A surge has to be of sufficiently high voltage to break down the dielectric at ordinary temperatures, since it only lasts for a fraction of a second, and can therefore have no appreciable effect in raising the temperature of the dielectric.

The next bogie which Mr. Vernier exposes, and to which I propose to refer, is the question of creosote. The objection to impregnating wooden troughing with creosote has been proved to be unfounded; as a matter of fact, there are 20 or 30 miles of cable laid in creosoted troughing in this district which has been in the ground for five or six years without any harmful action. Since creosoting is the only satisfactory treatment for wood buried underground, it is unfortunate that cable manufacturers held out against its use so long. I should also like to mention the expansion joint described by Mr. Vernier on page 332, and shown in Fig. 17. The troubles which led Mr. Vernier to design this joint were very serious, and on one particular route, namely, the 20,000-volt cable laid between Birtley and Peltor substations, it was practically impossible to keep the cable in service for more than a week or two together on account of failure of joints due to earth movements; in fact, I remember on one occasion two joints

were found broken down at the same time. Since the expansion joints were installed breakdowns have entirely ceased, although there is still a considerable movement of the earth along the route of the cable. I think nothing more than this need be said in support of the joint. Mr. Hunter.

There are no other main points in the paper with which I propose to deal, but there are a few notes which I have made here and there, and to which I would like to refer. On page 315 Mr. Vernier gives as a reason for not having more than two pipes in the width of a duct line the fact that there is a difficulty in dealing with the bend from the middle pipes in manholes. Another important reason is temperature rise. With more than two pipes the temperature of the cables in the middle line of ducts is apt to get high, and since the factor of safety of the cable for a given pressure decreases with increasing temperature, the current density of the cables in the middle of the duct line would have to be limited. The manhole shown in Fig. 2 is that adopted on the duct lines in connection with the cables crossing the river through the special tunnel at the Carville power station, and the arrangement certainly works very satisfactorily in practice. The principal objection is the additional concrete required where the pipes are splayed out as they approach the manhole. On page 318 Mr. Vernier says that Trinidad bitumen is superior to pitch for cable laying on the solid system. This is true, but it must not be overlooked that coal-gas has a very serious action on bitumen. On the same page Mr. Vernier refers to the evaporation of the thinning oil from pitch, the effect being accelerated if the pitch is exposed to the air. This is also true of vulcanised bitumen, and may readily be seen from the two samples shown, one of which shows how the oil has evaporated from the vulcanised bitumen covering of a cable drawn into a duct line where the air has access. The other sample is of a vulcanised bitumen, which has been laid solid for the same period. In this case the bitumen is as good as when it was first laid. The chemical action of wood bridges on the lead sheath of a cable, referred to on the same page, may be greatly accelerated by weak electrolysis, that is to say, a current so weak as ordinarily to be negligible. On page 319 Mr. Vernier refers to the fact that pitch does not always adhere to the plain lead covering of cables. I have not seen so much cable opened up as Mr. Vernier, but speaking of what I have seen I should say that it hardly ever adheres properly to the lead covering, and not at all in the sense that glue adheres to a piece of wood. In connection with the protecting cover of armoured cables on page 320, it is at first sight perhaps not clear why tiles should be preferred on the solid system and a wooden cover for armoured cables; the difference, however, is that, in the case of the solid system the tiles are directly on top of the trough, and any one disturbing them immediately exposes the troughing. In the case of the armoured cables there is 3 in. of earth between the cover and the cable, and tiles might be readily removed without the excavator being aware of the presence of the cable. I think every one will agree respecting the superiority of the method of jointing the cores of

Mr. Hunter. the cable by flexible braids shown in Figs. 10 and 11. In a coal-pit, where solder cannot be used, its advantage is obvious. As regards jointing, I have no hesitation in predicting that the joint filled with soft compound after it has been exhausted by a vacuum pump will become universal for high-pressure systems. Any one who has had experience of the trouble encountered with joints on high-tension cables, practically all of which is attributable to air or moisture, will certainly agree with this view. I may mention that one important advantage of the system is that the vacuum very thoroughly tests the workmanship of the jointer in plumbing the lead box, and this ensures that no moisture will have access to the joint or cable due to bad plumbing. An important objection to cast-lead sleeves mentioned on page 329 in connection with Fig. 13 is that they are frequently porous; in fact, it is not possible to employ them in connection with the vacuum joint on this account.

Mr. Fawssett. Mr. E. FAWSSETT: I am in entire agreement with the author's condemnation of the ordinary lead-covered cable laid solid. Neither of the safeguards against electrolytic corrosion are more than palliatives, as earth-plates can shunt the weak points only and reduce the rate of corrosion, and these are never less than 6 or 7 ohms per pair, usually 10 or more, and they tend to get worse with age. I do not see that it is possible to permanently insulate the lead sheath from earth, as, where there is any movement of the ground, any unyielding system could not remain intact. With reference to the expansion of the lead due to watts lost in the cable, experiments have shown that the lead only reaches about 10 to 15 per cent. of the copper rise, higher figures being obtained if two cables are laid in one trough. For 50° C. rise on the core very high-current densities may be allowed, if the excessive drop does not matter—a 0·0125 sq. in. high-tension 3-core cable may be run up to 6,000 amperes per square inch, a 0·05 at 2,400 amperes per square inch, and a 0·1 sq. in. at 1,900 amperes per square inch.

Professor Thornton. Professor W. M. THORNTON: With regard to breakdowns taking place some distance from where the short circuit was developed, this is quite simply explained by a mechanical analogy. In Fig. A, A is

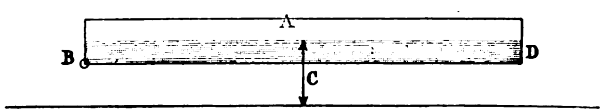


FIG. A.

a trough hinged at B, the distance C representing the voltage of the cable above earth. Imagine the trough filled with water, and the end remote from B suddenly dropped through the distance C, this being analogous to what happens in the event of a cable going to earth at D. If now before the water runs out of the trough it is suddenly elevated up to its original position, it is obvious that a wave of water or electric charge will be reflected with great violence along the length

of the trough towards B, and in the event of the generator voltage being at a maximum at the moment B is reached, an extremely high voltage may result. [Mr. C. FARADAY PROCTOR: From the frequency and other factors of the circuit it should be possible to calculate the distance from the point of the short circuit at which the cable would break down.] I agree that this could be done, but it would not be a simple matter. I believe that the electrical breakdowns in cables in the end are due to the effect of dielectric hysteresis. I should like here to show some oscillograph records of condenser current waves with marked hysteresis, as I believe this is the first dielectric hysteresis loop from a sine voltage. If the dielectric constant of the insulation remains constant the quantity of the charge is strictly proportional to the volts, and when the voltage falls part of the charge is left behind, which eventually falls, but lags behind the voltage. The cable breaks down in the same way as any other condenser. Plotting current values in the condenser against time we get a curve rising slowly in a straight line up to a certain point and then rapidly increasing, and this behaviour is characteristic of every type of condenser, except perhaps one made with mica. If the maximum point in the hysteresis loop is well on the way towards the yield-point in the case of an alternating-current circuit the maximum point is progressive, and there is a creep of hysteresis as well as of the quantity. This idea is based on Foster's theory of the breakdown of metals under repeated alternating stresses, and there appears to be a complete analogy between the electrical and mechanical actions. [Mr. P. V. HUNTER: This creep will account for direct-current cables standing so much better than alternating-current cables.] Yes; but under direct stress there is a more extended effect. Plotting the dielectric constant against time, however short the period, there is a given value for K. After the first charge the polarisation proceeds automatically. On discharging by short-circuiting there is first a sudden drop, and the charge then comes out at the rate at which it went in. All we have to do is to start the yield, and the polarisation increases automatically, so that, under voltage, there is reached a polarisation which is the same before all voltage gradients. We might expect from this that direct-current cables would break down more easily than alternating current. That they do not shows that the breakdown is due in alternating-current cables to a cumulative yield of the nature suggested, the strain creeping towards the end with great rapidity. Professor Thornton.

Mr. G. B. BURROWS: In regard to expansion joints the author has shown that in districts such as this breakdowns and serious interruptions of supply are inevitable unless discriminate use is made of some type of flexible—not expansion—joint. Four years ago I was faced with subsidence troubles which it was imperative to overcome, and it resulted—by co-operation with a fellow engineer—in the design of a flexible joint-box, the manufacture of which was taken up by Messrs. Callenders. The Bowden wire action was noticed by us, hence we used plumbed glands; experience has justified their use, as in one instance Mr. Burrows.

Mr. Burrows.

only, out of thirty-two such faults, have I found the lead of the cable appreciably thinned near the gland, this actual subsidence occurring within a few yards of the joint, and the thickness of the sheath was reduced from 0·17 to 0·121 in., the cable being 0·3 sq. in. 3-core high-tension wire-armoured paper-insulated. The box as originally designed allowed for a maximum expansion of 9 in., but they were so jointed up as to allow an initial pull of 7 in. or a compression of 2 in., the accommodation of which is fulfilled admirably. The main points about the box are :—

High insulation.
Ease of inspection.
Allows of disconnecting for testing purposes.
No sliding contacts.
Accommodates expansion and contraction.
Three years' hard service without a single failure.

Owing to unavoidable circumstances only six or seven are in use to date, but on one feeder section where three only are installed (the bad ground covering an area of 200 yards), faults due to subsidences were almost fortnightly occurrences previous to the adoption of this box, whereas not one failure has occurred since their installation three years ago.

Mr. Drummond.

Mr. A. L. E. DRUMMOND: All our cables are in iron pipes or conduits, and fortunately we have no trouble due to movement of the ground. Also as the currents carried are much too small to cause heating of the cores the temperature tends to remain constant.

Mr. Viall.

Mr. H. R. VIALL: I have listened with much interest to the particulars which we have heard regarding the new type of bitumen-sheathed cables, but it seems to me that there is a danger of the bitumen sheath becoming plastic and allowing the cable to sink, thus reducing the factor of safety on the underside of the cable. The flexible joint described by Mr. Burrows is also very interesting, but the cost would appear to be prohibitive.

Mr. Clothier.

Mr. H. W. CLOTHIER: With regard to pressure surges and the installation of cable-charging devices, Mr. Vernier says it is surprising to him to learn that cable-charging devices are still in use. It may be of further interest to him to hear that they are included even now in some specifications, much to the inconvenience of manufacturers who try to simplify switchgear as much as possible. Considered from a mechanical point of view, the introduction of auxiliary busbars and interconnections is very difficult to deal with satisfactorily, and I hope that the points brought forward in Mr. Vernier's paper may help to eliminate this complication in the future. The idea in installing cable-charging devices is to prevent an excessive pressure rise on an open-circuited cable when switching-in, such excess pressure being caused by oscillations which occur when there is a certain relation between the capacity of the cable and the inductance of the

Mr. Clothier.

machine in series with the cable. I believe it was proved many years ago that the phenomenon was more serious in cases where the machines had an irregular wave-form; in a bad case the pressure rise amounting to about three times the normal. Even in such extreme cases, however, it is questionable whether cable-charging gear is any use. It must be remembered that the increase of pressure is only of momentary duration, whilst cables and apparatus are always tested to double their working pressure, and sometimes three times the working pressure, for several minutes. No part of the system could stand its normal voltage continuously if it were unable to withstand a momentary pressure rise such as might be occasioned by switching-in an open-circuited cable without a cable-charging device. We have also to remember that a similar phenomenon may result from other operations than switching-in; for instance, the occurrence of a heavy short circuit, which is suddenly cut out, has the same effect on other parts of the system as switching-in, and the cable device cannot be put into commission in such cases. The correct policy, therefore, seems to be to insulate the system throughout with a fair margin of safety and to dispense with the cable-charging device. It seems to me that excess current-surges, such as are occasioned by a short circuit, are more to be feared, in that they make the conductors writhe out of shape in a way likely to damage some part of the insulation so that it breaks down sooner or later.

Mr. Bridges.

Mr. H. BRIDGES: Referring to the draw-in system, Mr. Vernier suggests that the arrangements of pipes in manholes, as shown in Fig. 2, page 315, is preferable to the arrangement shown in Fig. 1, on account of neatness and safety from falling covers. As regards the danger of manhole covers falling on the cables, this can be easily avoided by having the pit made longer and wider than the manhole cover, so that if a cover should fall, even with the arrangement of cables as in Fig. 1, it would drop clear of the cables. Mr. Vernier mentions that unsupported bends should be avoided. In my opinion, the distance from the end of the pipe to the first cleat should not be more than 4 ft. for large cables, and for smaller cables this distance should be shorter. The arrangement in Fig. 1 has many advantages which are not obtained in Fig. 2. In designing manholes there are other questions to be considered besides neatness and safety. One important point which appears to have been overlooked, is that after the pipes are laid and the manholes built, the cables have to be drawn into the pipes. If the arrangement of pipes is such that the work of drawing-in cables is going to be greatly increased, then it has been badly designed. The pipes and manhole should be arranged so that the least possible labour is required in drawing in the cables. The arrangement in Fig. 1 gives better facilities for drawing-in cables; this is one reason, and I think a practical one, why the arrangement in Fig. 1 is preferable to Fig. 2. I am afraid these are points which are often overlooked in the laying of pipes and building of manholes. The pipes should be arranged so that as near as possible a

Mr. Bridges. straight pull can be obtained in drawing-in cables, as it is obvious that if the pull has to be exerted round the edge of a pipe the friction is being added to, and therefore extra labour must be obtained to carry out the work, which means, of course, extra expense. Then again, if the cable breaks down, it is necessary to have the cable drawn out as quickly as possible. I have known cases where it has taken all day before it has been possible to draw out a length of cable owing to the pipes having been arranged in such a position that it was impossible to get a straight pull on the cable, nearly all the energy being spent upon drawing the cable round the pipe end. The pipes are generally laid and manholes built by one department, and the mains department have the privilege of drawing in the cables as best they can. Then again, with reference to the expansion and contraction of cables, Mr. Vernier states that with an increased temperature of 90° F. the conductors will expand 4 ft. 6 in. per mile and the lead 7 ft. 6 in. If this is the case, the arrangement in Fig. 1 is an advantage over Fig. 2, as these bends would take up the movement of expansion and contraction. In my opinion a coffin-shaped manhole would be the best, as the advantage of both arrangements would be obtained. In the laying of armoured cables in the ground, Mr. Vernier states on page 321, that on the Continent it is the practice to surround them with sand. This would, no doubt, add to the cost of laying, but it occurs to me that it would be an advantage in districts where subsidences are known to exist, as it would give the cable much more freedom to move, since the friction on the cable from the surrounding soil would not be so great as if the cable were surrounded with sand.

Mr. Harris. Mr. T. H. HARRIS: It is interesting to notice that after such a long trial the solid system has been abandoned, but I think the reasons stated are sufficient. The armouring which Mr. Hunter has described is exceedingly good. A cable which we are laying at present has a bitumen sheath, which does adhere to lead. The best protection for this type of cable is a wooden board, but this must be well creosoted. If it was proposed to run cable at 150° F. a lot of difficulties would be likely to crop up, since tape at this temperature changes its dielectric properties. Fig. 12 shows the type of joint which has been used for a number of years. It involves a lot of handling by the jointer, with consequent danger of moisture from his hands, and necessitated the tapes being boiled in oil, etc., on the spot. Fig. 13 eliminated the work of the jointer to a very great extent, but employed stars to spread the cores; these are weak points in any joint. Perhaps I might mention the type of joint we have recently introduced for extra-high-tension work (30,000 volts). It consists, essentially, of impregnated paper cylinders to insulate the ferrules and of a lead sleeve plumbed to the sheath of the cable. The sleeve is filled with compound of the consistency of vaseline when cold but very liquid when hot. The exclusion of all air and moisture is secured by exhausting the sleeve—prior to introducing the compound—by means of a petrol-driven air-pump, which is made very compact and portable to render transport easy. A

very high degree of vacuum is thus obtained and all moisture is got rid of by heating the sleeve whilst the pump is working. The compound, when poured into the joint, so treated is able to flood the inside of the sleeve, neither moisture nor air being present. I have never met a high-tension joint which could be condemned on the point of workmanship. Some breakdowns have been of a novel character. One joint made as in Fig. 13 had been filled with about 35 lbs. of compound. Upon opening it, it was found that the whole of the compound had disappeared; the insulating tape had also disappeared, indicating that the joint had been subjected to a very high temperature. In another case, upon opening the joint, we found that not only had the compound disappeared, but the pitch with which the joint was surrounded had leaked into the sleeve and had taken the place of the compound. The compound had evidently been previously destroyed, as in the first case. This was a 20,000-volt joint and had run for some time quite satisfactorily at that pressure, though only insulated with pitch. It may be of interest to note that we used to make these joints with tape and mica interleaved, but later decided to leave out the mica. I am not sure, however, that that was a move in the right direction, as although the tape with mica might afford less resistance to perforation at low temperature, at high temperature they both together gave decidedly better results. This indicates that all tests and joints should be carried out at the highest temperature at which the cable will be run. Mr. Harris.

Mr. G. L. PORTER: I did not intend to join in this discussion, but a remark of Mr. Clothier's made me wish to add something. He stated that clearing a heavy short circuit gives the same effect as switching in a length of cable. Recently it has been shown by the oscillograph that an oil-break switch does not by any means necessarily break the current at zero-point, and any sudden break in the current in a cable causes the energy in the circuit to oscillate between the electromagnetic and electrostatic states until it is dissipated. In a line composed of a length of overhead line in series with a short length of cable, on breaking circuit the cable has to absorb all the energy from the overhead line. As, however, the capacity of a short cable is small, high pressures result. With regard to the question of troughing, I had some experience of railway signal work and remember one case where plain rubber cables had been installed in plain wood-casing laid in ballast, but, of course, this did not last long, and when lifted the rubber and casing were found to be almost destroyed. With regard to the question of pressure testing, at one time in the regulations of the supply company it was stated that a length of cable or a choking coil had to be inserted in the low-tension side of the testing circuit in order to prevent an undue rush of current in the event of the testing apparatus breaking down. I found, however, when testing the sparking distance with horn arresters, the choke coil completely altered the shape of the wave with the result that the maximum value for a given R.M.S. value was altered. Without the choke coil it was found that 9,500 volts were required to spark across a given distance, whilst with Mr. Porter.

Mr. Porter. the choke coil in circuit only 8,000 volts were required to break down the same gap. This experience shows that considerable care is necessary in selecting gear for testing purposes where there is a chance of the wave-shape being altered.

Mr. Addison. Mr. G. B. ADDISON: Mr. Vernier seems to have come to a very definite conclusion with regard to the solid system and armoured cables; he stated that he did not think the North-East Coast companies would lay any more high-tension cables on the solid system Armoured cables are nothing new, for I should say they belonged to the methods of the earliest days of laying mains. I cannot speak from experience of armoured cables laid direct in the ground, but I think it is pretty generally admitted that very few engineers speak highly of them who have had such experience. I should prefer a cable laid solid with earthenware troughing, porcelain bridges, and pitch of correct proportions, or if money is no object, bitumen; it makes a more lasting job and offers better protection to the cable. With the improved coverings adopted for armoured cables mentioned on page 321, I think that in waterlogged ground, or where decomposed organic matter exists, these coverings will rapidly deteriorate. My experience of the solid system is that many of its evils are accentuated by carelessness, and the craze for doing it quickly and cheaply. This the author mentions on page 320, and rather excuses it by saying that good workmanship is exceedingly difficult to attain. I have seen good work done, and I go further to state that it can be done with a minimum amount of care. I agree with the author that where earth movements and subsidences are likely to occur, then armoured cables are most suitable. There is a strong point over which I would prefer the solid system to armoured cables laid direct in the ground. When a cable fault develops it invariably bursts the outer covering. If it occurred on an armoured cable laid direct in the ground, and this being waterlogged, one would expect to find much of the cable to be destroyed by water between the two joints. Armoured cables will make the location of faults much more difficult, for cable faults that have come under our notice on the solid system usually burn out and become open-circuited with the insulation sufficiently high to permit of easy location. With armoured cables this would not be the case; the cores would still burn out and open circuit, but would earth also in the wet ground, thus rendering localisation extremely difficult. I would prefer wrought-iron plates put over conduits laid under tramways or roads where concrete is extensively used by the public authorities.

With regard to the expansion joints, I would like to ask Mr. Vernier whether the movement that takes place in his expansion joint is likely to reduce the dielectric strength of the insulation of the cores in the adjacent cable. As was shown, the movement that takes place is not uniform, and from this I should imagine there will be a chafing or rubbing taking place between the cores that may be even sufficient to crack the paper and cause the cores to short circuit. It would appear

that, for subsidences on a large scale expanding cable would be necessary in conjunction with the joints. I congratulate Mr. Vernier on the design of his joint. It is delightfully simple and should prove equally efficient, and meet admirably the conditions it has been designed for. **Mr. Addison.**

Mr. J. W. Hogg: With regard to the glazed bridges, I would prefer unglazed vitrified bridges, boiled in filling-in compound and allowed to cool before placing in troughing. I quite agree with the author's remarks on solid systems, and that the armoured cable is the most satisfactory for transmission mains, though if laid through made-up ground, etc., I would prefer it laid solid, even with cables such as are now being adopted by the power companies on the North-East Coast which have the mechanical protection sheathed with a bituminous covering, etc. I have had some experience of cable to a similar specification which I first used in connection with the laying of a main through a river bed (which was really nothing more than an open sewer carrying the discharge from dye, bleach, and soap works, in addition to common sewage matter) as far back as 1902, and later, in 1906, I had a similar cable made for laying in the beds of canals in India, in both cases with satisfactory results. With reference to joints, Fig. 15 is a practical joint which is hard to beat over an extended district where one is often in the hands of one's jointers, etc., and knowing this joint to be available, it would require much persuasion to cause me to take up other forms which require highly skilled workmen. As regards the joint compound leaking above the copper core of the cable, I should prefer to have the strand impregnated throughout with a similar compound to that used as joint-filling compound. Regarding subsidences and over-running, I quite appreciate the author's difficulty and the way in which he has attempted to overcome it with expansion joints, and whilst hardly dealing with transmission cables, I would like to mention some of the troubles I have experienced on single feeder cables abroad, of sectional areas of 0·8 sq. in. and over, laid solid and working in a temperature varying from 75° to 100° F. 3 ft. below the ground and at high-current densities. I found it necessary to put in expansion joints to every length of cable and allowed approximately a 3-in. movement each way per 110 yards of a 1·0 sq. in. cable, or 6 in. movement per joint, a 0·5 sq. in. cable being allowed 5 ft. per mile, and after a number of experimental designs evolved one which proved satisfactory, but which could not be used as a disconnecting point; it will, however, be seen that a considerable amount of space is required in the boxes which were designed with reducing-pieces to the troughing and divisions between each joint. Surging, as the author says, is fortunately not common on systems with a high factor of safety, but we must necessarily treat the weakest point in the link when arriving at the actual factor in practice, as those who have had to take up the working of extensive networks quickly realise should the standard of construction have been in any way lacking. **Mr. Hogg.**

Mr. Beaver.

Mr. C. BEAVER: I am much interested in the results the author has obtained with his expansion joint-box, but should like to ask whether the breakdowns on cables, apart from the joints, which he states to have been frequent prior to the introduction of his box, were not invariably near joints, *i.e.*, where a part of the cable which was free to move was in close proximity to another part in which the movement was limited or restricted. This has always been my experience, and, in fact, it is difficult to see how the expansion joint can affect or relieve any stresses set up by expansion and contraction of the cable except in its immediate vicinity. The joint is not the seat of the heating, and the breaking of the joint is due to the movement of a certain length of cable on each side of it; in other words, it is not so much a matter of the relative movement of conductors and box, as of the bodily movement of the cable outside the box. The preventive measures I have hitherto found successful have been to provide a loop of cable in the manhole on each side of the joint-box, so that the box only formed an integral part of the expansion-piece. In bad cases, and where space was limited, joints made with tail end-boxes connected across by loops of rubber cable, and free to move on shelves or rails have been found successful. Such methods are, of course, cumbersome as compared with the author's method, and for this reason I am anxious to hear as to what happens to the cable sheaths in the vicinity of the box. Lead sheaths, in particular, are easy to expand, but if deformed in the least by such expansion, they will take a permanent set which will be exaggerated by each successive expansion, and soon become fractured. With regard to the filling of joint-boxes and the author's preference for an oily or viscous compound, it is obvious that compounds of this character will be necessary for joints in which expansion arrangements are provided. For ordinary work, there is much to be said in favour of solid compound with fairly high melting-point. With such compound all questions of leakage—which, by the way, are not inconsiderable where cables are run at high-current densities—are swept away. On the other hand, it is more difficult to ensure perfect filling of all interstices in the joint and the box. These difficulties are not, however, by any means insuperable. Some time ago I made a wide series of experiments on this box-filling question, including vacuum and pressure methods of filling. As a result, I came to the conclusion that the simplest and most certain method was to introduce compound into the box by means of a funnel screwed into a plug-hole at the highest point of the box. The only precautions thereafter to be observed are that a head of compound is maintained in the funnel at a higher temperature than the compound which is cooling down in the box, and that this condition should be maintained until the compound in the box has cooled down to somewhere near its solidifying point. The action briefly is, that the entrapped air and gas bubbles occluded in the compound escape *viâ* the funnel, and their place is taken by compound from the funnel. The physical contraction of the compound in the box due to cooling is also compensated for by drawing com-

Mr. Beaver.

pound down from the funnel. In this way the boxes can be absolutely and with certainty filled with a compound having such a melting-point that working temperatures do not displace it in any way.

I should like to say a word on the subject of bridges and the author's preference for glazed earthenware. I prefer unglazed earthenware bridges, because they can easily be obtained of such a quality that they do not depend on glazing for moisture-resisting properties, and the matt surface helps the adhesion of the trough-filling compound. With regard to asphalt bridges and the idea that they become crushed out of shape by the weight of the cables, I have not only kept cables under observation which have been laid on asphalt bridges, but I have experimentally exaggerated the worst conditions by laying steel bars in imitation of cables so as to get not only a great weight per length, but a great concentration of weight owing to small diameter of the steel bar as compared to that of a cable of equal weight per length. I have found no perceptible crushing of the bridges up to a weight of about 8½ lbs. per bridge. These bridges certainly soften to some extent when the hot filling compound is poured over them, so that possibly any pressing down which the cables receive may be responsible for the idea that the weight of the cable crushes them. They are, of course, much more easily broken in handling than porcelain bridges. I agree with the author that wood bridges should never be used, but I would add that my experience as regards their supposed attack on the lead sheathing of cables is that it is more often a matter of the wood bridge forming an electrolytic path than of simple chemical action due to the products of decay of the wood. So far as armoured cables laid direct are concerned, I quite confirm the author's remarks as to the favourable results as regards preservation in the case of dry, sandy soils. I recently examined some rubber-insulated cables which had been laying in sandy soil for the past fifteen years, the steel tape armouring of which was not even tarnished. A layer of well-punned clay is, as the author states, a decided protection to cables in bad soil. As regards the improved coverings which the author describes as now being used by the North-East Coast power companies, I should like to mention that my firm made lead-covered cables with a coating of vulcanised bitumen over the lead about thirteen years ago for one of our largest railway companies, the object being to afford the lead special chemical protection on account of it being laid in the track ballast. Also, for several years past the Glasgow Corporation have had a certain type of cable sheathed with vulcanised bitumen over a lead covering, and then a second lead covering applied over all. I quite agree with the author that the slight extra expense entailed by special preventive measures of the kind described constitutes a good investment. The laying of cables in chalk or limestone is not a condition commonly met with, but as a matter of interest while on the subject of soils, I would mention that I have found calcium carbide formed as the result of a cable breakdown where a comparatively large arc has occurred. The

Mr. Beaver. limestone and the carbonaceous matter from the filling of the cable trough, together with the arc, provided all the conditions necessary for the formation of the carbide, which, of course, when wetted, gave off acetylene quite freely.

Touching on the question of electrolysis, there is no doubt that continuous bonding and judicious earthing of metallic sheathing is a much more definite and controllable method than the alternative of insulating the lead sheath. Unless the lead sheath is treated as a live conductor, and is insulated accordingly, there is always the possibility that a local failure of its protective covering, whatever it may be, may lead to leakage-current passing *viâ* a limited area. As this entails a high-current density, the consequent local corrosion which may ensue will be very severe, so that failure will be likely to occur before there is a chance of discovering it. No conduit into which water may leak, much less one which will absorb water, can be regarded as a preventive against electrolytic corrosion.

Mr. Dawson. Mr. J. E. DAWSON: With reference to Mr. Vernier's remarks on electrolysis on page 330, and the question of the bonding of all armoured cables and joint-boxes, I may say that although it has now become almost standard practice to bond everything up solid everywhere, it by no means follows that in ordinary low-tension transmission and distribution it is necessary or even advisable to go to this additional expense; the fact of its being generally adopted is, of course, not of itself a proof. I know of several supply undertakings in various parts of the country where everything is bonded up most elaborately, no expense being spared, and yet a good deal of trouble has been experienced with electrolysis: on the other hand, I know of instances where the lead has been broken at every joint and insulated from the joint-box as much as possible (thus omitting to provide any gratuitous earth return for tramway or other leakage currents), and yet in these instances, which should by all the rules prove examples of how not to do it, there has not been the slightest trouble. At West Hartlepool, where practically the whole of the cables are lead-sheathed steel-taped (triple concentric for distributors and concentric for feeders and singles for neutral-wire feeders) all the cables are laid direct in the ground, the lead and armour is broken at every joint and service connection, the cable where it enters the joint-box being fitted in impregnated wood bushes, and the whole being well smeared over with high-insulation box compound. These cables have now been laid down nearly twelve years, and so far there has not been a single fault due to electrolysis, not, however, because during this period there has been any miraculous freedom from the usual occasional earth leakages inseparable to ordinary central station supply; on the contrary, there has been just the usual amount of earth currents as might ordinarily be expected, both on our own supply undertaking (principally on consumers' installations) and also on the local tramways. This policy of splitting-up the lead and armour into as many separate lengths as possible, with as much resistance between each length as possible, was not adopted in the first

Mr. Dawson

instance hastily or without the various pros and cons being carefully considered, but was adopted deliberately on the advice of one of the most eminent electrical experts, and although this policy does not happen at the present time to be fashionable, it has none the less in this instance proved a thoroughly sound and efficient one; and bonding, with all its additional expense in material and labour, could not possibly have improved matters, whereas it might possibly have been the means of introducing troubles which have now been avoided, so that it is as well to remember that although there are points in favour of bonding, there are also points against it. It seems to me that by bonding everything up solid we are attempting to provide a competitive earth return circuit for any earth leakage currents, as compared with the local earth and the water companies' mains, and as it can never be of quite as low resistance as the latter, particularly if the neutral wire of the supply is earthed at the generating station on to the water mains, the result will only be that instead of practically no current travelling on the lead of the cable, as would be the case if the lead was broken at every joint, a large proportion of the current, depending, of course, inversely on the resistance of the respective circuits in parallel, will travel along the lead until it reaches some point in close proximity to a water pipe; it will then split up, a large proportion leaving the lead of the cable for the path of lower resistance, thus damaging the cable through the electrolytic action set up, and completing its return circuit to the generating station, *viâ* the water pipes. This action may, of course, very probably occur at several places on the run of the cable; in fact, wherever the resistance of the respective parallel paths —water-pipes and lead of cable—are such that the circuit *viâ* the water-pipes offers the lower resistance.

Then there is the question of the current-carrying capacity of the lead bonds, etc., and fusion. I believe that a good deal of the trouble that is put down to electrolysis on bonded systems is not really electrolysis at all, but fusion, as, owing to the low-resistance path provided by the bonding of the cables, in the event of, say, a momentary dead earth, enormous currents may be encouraged to flow along the lead sheathing and across the bonds, arcing and fusing at every loose or imperfect contact on the route, whether it be in the bonding, earthing-plates, or accidental cross-connections with other earthed services, such as gas or water pipes; then afterwards, sooner or later, moisture creeps, and there is another fault which is attributed to electrolysis. A striking instance of the enormous currents that may momentarily travel along the lead sheathing of bonded cables was given by Mr. G. L. Black, of the Glasgow Corporation Electricity Department, before the Glasgow Local Section, January, 1906, who cited a case where, on a fault occurring on a cable some distance away, a lead bond 2 in. × ½ in. in sectional area, of an exposed joint-box near which he happened to be at the time, instantly went off in a puff of smoke, and stated that the current flowing momentarily would probably be between 6,000 and 8,000 amperes. This occurrence also incidentally indicates how

Mr. Dawson. difficult it is really to know when the bonding and earthing is, and is not, in a reliable and efficient condition.

Discussion before the Glasgow Local Section on April 11 and May 16, 1911.

Mr. Mitchell. Mr. R. B. Mitchell: I am surprised to learn that Mr. Vernier advocates the use of cast-iron pipes in duct systems. We, in Glasgow, several years ago made considerable use of cast-iron pipes, and our experience with them was very unfortunate. We found that although the lengths of pipe were bonded together as carefully as possible, and the whole well earthed, it was impossible to keep the lead from disintegrating at points of contact with the iron, and in course of time at these points the lead became quite eaten through. We then gave up the use of cast-iron pipes entirely. Mr. Vernier also advocates cast-iron troughing for solid systems where cost is not a consideration. We have not had good results in the past with these troughings with lead-covered cables. In the old days I think the tendency was to make the iron troughs rather small to save expense, and the consequence was it was not possible to lay the cables in without having them in touch with the troughs at some points. When the insulation of the cable broke down it might be at a considerable distance from the points of contact between the lead and troughing, the lead became alive, arcing took place at all these points, and instead of one fault there were probably several to contend with. As regards filling material, Mr. Vernier prefers to use bitumen rather than pitch, in spite of the fact that the former is 2½ times dearer. In Glasgow we have used pitch for this purpose for over eight years, and have never had any reason to regret it. In all cases where we have had to open up we have found the cables in excellent condition. Recently, however, we have been using not pitch only, but a mixture of pitch and finely powdered whinstone. We find with the mixture a great increase in strength, toughness, and tackiness, as compared with pure pitch and the cost per cubic foot is reduced considerably. I have carried out experiments to find out what would happen with this material if any subsidence or change in the position of the cable took place, and I found it possible to bend a 6-ft. length of this mixture into the form of the letter U, and then bend it back into the same shape in the reverse direction without the least sign of fracture. Passing on to the question of the making and insulating of joints on extra-high-tension cables, I have on the table a model of our latest type of high-tenison joint. Up to the present we have used a type of joint which followed pretty closely Fig. 14 of the paper. In the new type we have discarded the use of tape entirely, using instead a porcelain sleeve divided into three compartments, one for each core of the 3-phase conductor. This sleeve is slipped over the ends of one of the cores to be jointed together. The joints are then made with copper sleeves in the usual way. The porcelain sleeve is then brought over the bare parts and held in place by a flat piece of

porcelain introduced between the conductors. The lead sleeve is then wiped on and filled up with E.H.T. compound. The advantages claimed for this arrangement are: (1) there is no tape used, (2) the conductors do not require to be splayed out to wind tape on, etc.; we found that when they were disturbed in this fashion the paper insulation was apt to crack unless very carefully handled. We made careful experiments to find if the compound entirely filled the compartments enclosing the conductor in the porcelain sleeve, in which the space is very confined, and we found that it did so, although the compound used was a fairly solid one at ordinary temperatures, and that the joint, so far as that was concerned, was a thoroughly reliable one. We have not one working at present, but we hope to have one soon. Mr. Mitchell.

Mr. D. M. MACLEOD (*communicated*): Mr. Vernier on page 333 of his paper refers to the great strains which come upon cable joints where these are at times loaded up to high-current densities, either in cases of emergency or in order to avert the heavy capital expenditure in laying additional cables. He cites the case of a cable laid in the ground and jointed up originally at a temperature of 60° F., pointing out that with a safe increase of temperature of 90° F. the conductors will expand 4 ft. 6 in. per mile. This amount of movement shows the importance of making provision for free movement at all cable joints, apart altogether from considerations of subsidence. It seems to me that the joint patented by Mr. Vernier, while it is a distinct advance on the usual form of straight joint, hardly meets the conditions. I understand that a movement of only 3 in. is provided either in the form of contraction or expansion. On the Clyde Valley's distributing system we have, for the past three years, been making a practice of providing large expansion bands formed in the same manner as the expansion pipes in a steam-pipe range, with an ordinary straight joint at the top of the bend. This bend is surrounded by an ordinary brick pit of ample size, and by this means we are enabled to provide for a movement of several feet. Formerly we suffered very severely from subsidence troubles, but since taking the steps indicated we have had no further trouble from this cause. I might add that in our Carfin district the movements due to subsidence are so great that there is not the slightest doubt that Mr. Vernier's joints would prove entirely inadequate to meet these conditions. Mr. Macleod.

Mr. W. W. LACKIE: I am practically in agreement with all that is in the paper. If there be room, or rather, width of street, by all means let the mains be laid solid. Where there is not width of street the draw-in system has to be reverted to. It is true that breakdowns due to faulty manufacture are very few, but the converse is also the case, that when a fault does occur all evidence of what was the cause of it is burned out. Mr. Vernier is rather contradictory in reference to his draw-in system. He says that with the use of bitumen fibre conduits, on account of the flush joint of these, less space is taken up and a good deal of concrete can be saved. In the next paragraph he says that earthenware pipes provide greater safety because they give Mr. Lackie.

Mr. Lackie. double the thickness of earthenware wall and greater thickness of concrete. In Glasgow we have a nest of 20 ducts 4 × 5 and have no difficulty with them in separating out the cables at the manholes in a safe and neat manner. This is largely due to the shape of the manhole adopted.

In connection with the solid system the tramway department of this city have drawn in some lead-covered cables on which there is a double covering of lead ; that is, the cable is first of all lead sheathed in the usual way ; this is insulated with tapes and on the top of the taping a second sheath of lead is drawn. I understand that a distinct insulation is got between the two lead sheathings. This would ensure that no electrolytic trouble takes place on the inner lead. We have tried troughing treated with Stockholm tar, creosoted troughing, and Haskinised wood. Stockholm tar is little or no protection to the wood, but creosoted and Haskinised wood have proved quite satisfactory. We have always made certain that the creosoted wood was perfectly dry before using it. For many years now we have used pitch and pitch oil for filling-in compound. We were satisfied that this was better than bitumen for many reasons. Pitch has been used for the protection of iron and lead pipes in the gas department for forty years. The only point upon which we were not satisfied with pitch was its mechanical strength, and for some years back we have experimented with mixtures of pitch and talc, pitch and whinstone dust, etc., and have now adopted pitch and whinstone dust. I consider pitch is superior to bitumen for running-up cables for the following reasons: If the cable or troughing is at all damp, where hot bitumen is poured it froths up and gives anything but a solid job. The specific heat of bitumen is 0·8 as against 0·5 for pitch, and consequently the use of bitumen heats up the cable very much more than is the case with pitch. We have also recently got cable supports made of pitch and whinstone dust and are trying these in place of porcelain. I congratulate Mr. Vernier on his jointing methods. They undoubtedly have supplied a solution to the question of expansion and subsidence. Of course, a standard cable when heated does to a considerable extent take up the expansion of the cable on the lay of the different strands.

The only new point that comes to my mind that has not been referred to in the paper is one of considerable importance, and that is filling up the spaces between the different wires making up the cable, with some plastic material so as to exclude all air from the inside of the cable and prevent water or moisture from travelling for great lengths along the cable. If this is not done, it has been found that when the cable is run up solid with hot pitch or bitumen, a considerable expansion of air inside the conductor takes place, and if the end of the cable is sealed up while the cable is hot, the air-pressure inside the cable, on cooling, is less than that outside and a pinhole may draw in a considerable amount of moisture along the cable. For the protection of our extra-high-tension mains, on the top of the wooden troughing, such as is illustrated on page 317 of the paper, we have laid

common flat iron 7 in. × ¼ in. thick in 3 and 4 ft. lengths. This will stop a navvy's pick or any other pin being driven into the ground. Mr. Lackie.

Professor F. G. BAILY: Could slag or glass wool not be used in place of cotton, jute, or hemp, for filling and packing at glands or bushes of joint-boxes? It would be chemically inert, and it would soak up the pitch quite as much as is required. It would not rot like vegetable material, and it would be more absorbent and softer for packing than asbestos. I should also like to know whether in the expansion and contraction of cables from heating and cooling there is any sign of the lead not going back when it has gone forward, because I have known in connection with combinations of lead and iron pipes, for example, that after subjection to heating and cooling the lead would thicken up in some places and be thin in others, and possibly the same action may occur in cables. One other point I might mention. Mr. Vernier has laid great stress in the creeping-in of moisture in unlikely places. That reminds me of an old experiment I once made. Thinking to invent a very satisfactory filling material for junction-boxes, I prepared a mixture of resin oil and sand, which I thought would not only have the density of the sand but would have the non-hygroscopic quality of the oil, so that any water that came in through the lid would remain on the surface. On putting water on the surface of the mixture, however, I found that the water gradually, grain by grain, percolated through the sand, displacing the oil, until I had practically wet sand, which, of course, is quite a good conductor. I imagine that the mixture of pitch and whinstone dust that Mr. Lackie uses ought to be kept fairly hard, or he may experience the same result that I did. Professor Baily.

Mr. E. G. TIDD: In a paper of this kind the portions that specially appeal to the individual are references to work with which he has been more or less associated; the small portion of the paper which particularly appealed to me is Mr. Vernier's reference to the bitumen fibre conduits which he states are much used in America. About 40 miles of this duct have within the last year or two been laid by the Glasgow Corporation Tramways Department, and about a similar quantity by the Edinburgh Corporation. I thought it might be of interest, and so have here some further samples, which I have placed on the table. Mr. Vernier showed what is termed the "socket joint duct" only. I have also placed on the table some of the more recently introduced "sleeve joint ducts." The former are generally used for laying in concrete, whereas the latter can be laid direct in the ground. As Mr. Vernier explained, the joints are made watertight in the case of the socket joints by taking a 3-in. wide strip of unbleached calico of sufficient length to enable the ends to overlap, dipping it in hot compound and wrapping round the joint, a further compound being applied to the outside with a brush, if necessary. In the case of the sleeve joint duct, it should be noticed that the joint is made with a slight taper. It is made absolutely watertight by smearing a thin solution of linseed oil and whiting, or other suitable compound, over Mr. Tidd.

Mr. Tidd. the ends before pushing them into the sleeves. As both the ends of the ducts and the inside of the sleeves are carefully tooled this makes an absolutely watertight joint. Amongst other claims for this duct are the prevention of mechanical injury to cables in drawing-in, due to sharp edges and hard pimples which occur in stoneware duct. In the case of the Key fibre duct, as the joints are accurately turned, practically perfect alignment is insured, added to which the nature of the material is such that it is rubbed smooth by drawing the cable through it, and a good lubricating surface is provided, so that incidentally it is possible to draw a given length and diameter of cable through a considerably smaller duct, and with less strain than is required where stoneware duct is used. Mr. Lackie referred to the fact that this duct could be laid closer together than stonework ducts as a disadvantage on account of the risk of a short circuit from one duct to another, as he had known to occur in multi-way duct; but I think that if Mr. Lackie considers the matter for a moment he will see that the two cases are totally different. In a multi-way duct there is a single wall between the two conductors, and it might be very likely for a flaw to occur in that wall, but with two separate ducts, however close together they were, it seems to me to be quite impossible. A further question which crops up in connection with ducts is that of electrolysis, and whatever may or may not take place in connection with stoneware ducts, the bitumenised fibre duct is absolutely immune from any troubles of this kind.

Mr. Vernier goes on to criticise the solid system and the advantages of wood and earthenware troughing, and he makes some criticisms in regard to the latter on account of the pitch or bitumen not adhering to the glazed surface. He also criticises wood troughing so far as its preservative treatment is concerned. Cast-iron troughing also comes in for some criticism. I have placed a fourth kind of troughing on the table, viz., the Key fibre troughing, which, as will be seen, practically consists of the duct which I have been referring to, made into a trough by taking out a section to form the lid. This seems to meet practically all Mr. Vernier's various objections. There is no risk of creosote doing any damage; there is no glazed inside to prevent the filling adhering to the surface, rather the contrary, seeing that the filling and the material have very much the same constituents, which enables the two to combine in an absolutely perfect manner.

The Chairman. The Chairman (Mr. Sam Mavor): Mr. Vernier's paper and the discussion which has followed are an indirect testimony to the excellence which has been attained in the art of cable manufacture. The difficulties of the mains engineer appears to be associated with the proper laying of the cables, and especially with the proper jointing of them; the cables themselves appear to be almost perfect. I had occasion some months ago to go underground at the Hulton Colliery, where the great disaster occurred in December. I went down below with a number of officials a few days after the explosion, and found the cables in the mine buried under many thousands of tons of rock which

had fallen from the roofs of the roadways. The cable was 500-volt three-core armoured cable, and it is a very interesting fact that although nearly the whole cabling system in the district of the mine most affected was buried under immense falls of rock, we tested the system from end to end and found the insulation practically perfect. The lowest insulation was 50,000 ohms, and that was with all the boxes connected. That is a tremendously strong testimonial to the mechanical qualities of lead-covered and armoured cable. The Chairman.

Mr. C. VERNIER (*in reply*): Mr. Snell asked whether there was not a possibility of leaving air spaces by using the vacuum method of filling joints. With a 29·5 in. vacuum I do not think there can be much air left, especially when the vacuum has been maintained for 40 minutes, and considering that it takes only 30 seconds to attain this vacuum. With the constant warming which takes place there should be no possibility of air being present at all. Mr. Snell also referred to temperature limits and current densities at 20,000 volts. I am afraid I have no figures on that point. All I can say is that it is possible to run paper-insulated cables to a temperature of 156° F. continuously, but the current densities corresponding to this temperature have never been fully determined for various thicknesses of insulation and for the various types of cables and under different conditions of laying. There is no doubt that a great deal of experimental work and research will have to be done on this question, and similar questions, on the behaviour of cables. Such research is very much needed. We power engineers are, I am afraid, rather too busy to investigate questions of that sort; but if the Institution should at some time go in for research in the way that other institutions do, we could supply them with any number of problems for investigation. Then Mr. Snell referred to current densities of 1,800 amperes per square inch. That is a question which depends entirely on the size of the conductor, and he did not state what section of conductor he had in mind; but this current density is well within the limit for a 0·05 sq. in. 20,000-volt 3-core cable. Mr. Welbourn referred to lead-covered cables as the only means for doing high-tension work. I do not think there is any question that at the present time the lead-covered cable is the only feasible cable to use. With regard to the life of cables, he asked what evidence I had for stating that 20 or 30 years was their probable life. I have no evidence except what he mentioned himself, that some cables have been at work for 20 and 22 years. But there again it is all a question of research. I do not think 20 years can be quoted as the life of a cable, because it is a question of the voltage a particular cable may be working at. Mr. Ferranti has told me this evening of some cables, between Deptford and London, which are still running, which were put in 22 years ago. Those are 10,000-volt cables. The cables referred to by Mr. Welbourn were probably low-tension, and that makes all the difference. What the life of a 20,000-volt cable will be I do not think any one can predict with certainty at the moment. Various changes may take place in the cable over long periods of time, Mr. Vernier.

Mr. Vernier. and I do not think any one would commit themselves to saying what the life will be. There is, for instance, the dielectric hysteresis; there are possible changes in the insulating properties of insulating oils under continued high temperatures, from running at high-current densities, and other problems which affect the question and require investigation. I very strongly endorse Mr. Welbourn's remark that the continuity of the armour as well as of the lead must be maintained. That, I am afraid, is a point that is not often as much appreciated as it should be. It is a very common experience to find people who take care to maintain the continuity of the lead, but who leave the armour to take care of itself. They just bind it off at the end on to the jute, and do not make it continuous. It is possible to get quite respectable voltages induced in that armour if it is not bonded to the lead frequently, at the joints particularly. I also agree that after earthing a cable, one should not sit down and wait and see what happens. Conditions do alter, and, as mentioned in the paper, far more can be done by checking the conditions of running and providing against those conditions. For instance, if a certain system of earthing is carried out, as Mr. Trotter has mentioned, the earthing should be done at the most negative points. That is what we are doing ourselves, but the method I mentioned in the paper has been used very extensively I understand. It saves testing—that is one of the chief reasons for using it, but one should not sit down and think that everything is going on merrily. On a big system, especially on a power system which covers large areas, all sorts of people commence starting up a small tramway here and a small tramway there, or a railway company makes an extension, so that the distribution of the earth currents is altered considerably. It is necessary to test periodically, and to keep in touch with these people, so that they will run their system as it ought to be run—that is, put their negative feeders at the proper place and maintain their distribution as it should be. With regard to the braided joints, the tests mentioned were made on a 0·1 section. Mr. Highfield made a rather interesting suggestion, that we should use direct current for pressure testing the cables. It would be extremely convenient in one way—I mean the testing of very long lines of great capacity requires transformers of a considerable size. The A.E.G., in testing these 20,000-volt cables insert a choking coil, in parallel with the cores of the cable, for the purpose of cutting down the capacity current. The only difficulty to my mind is how to get 300,000 volts direct current readily. It is not a very easy thing to obtain.

Mr. Patchell rather took me to task about the Board of Trade earth shield. I have not the rules with me, but to the best of my recollection the Board of Trade regulations state that one shall take steps to prevent the ground becoming charged in the event of a fault. That may be done, either by the use of a copper shield, or alternatively, by armouring. I do not think that the Board of Trade really insist that there shall be a copper shield or an armouring. If it is possible to find some other method of preventing the ground from becoming charged,

I think the regulation covers that. Mr. Patchell also asked whether it was possible to draw water by the vacuum method. The reply I made to Mr. Snell's remark applies here also. I was much interested in Mr. Roger Smith's remarks about the Howard troughing, because I had heard of the use of it on the Great Western Railway, but I had not any very definite particulars. I am not at all sure, but I have some idea that a pressure test was specified on that particular cable, and if Mr. Smith will kindly mention whether that is so, and if so, the results that he obtained between the lead sheath and earth in that troughing, it would be very interesting to other possible users. If I understand rightly, the whole of the troughing is laid on a concrete bed. [Mr. ROGER SMITH: That is so.] That would, of course, tend to keep the faults down considerably. The troubles on railways are very severe owing to the vibrations. I may say that on a similar railway system the faults from vibration represented about 20 per cent. of the whole, and it is becoming quite a serious question—that is, with a solid system and not with armoured cables. I do not know of any case where it has occurred with armoured cables. The construction of a concrete bed is a very serious capital item, and I am afraid it is not everybody who can afford to lay it down. Mr. Howell asked: Why use concrete with ducts? I hardly think that any one would care to use ducts without concrete unless they had sufficient mechanical strength to resist external damage without it. Then again, I doubt whether thickening up the wall would be sufficient, at any rate unless the system is fitted with some of the very latest types of instantaneous protective gear, because with ordinary relay systems, two or three yards of cables, conduits, and everything else, can very often be burnt out in clearing a fault. The cost of draining is certainly a big item, but in some cases it has been found well worth doing. It depends very much on the situation of the ducts. Ducts may get filled up with 3 or 4 ft. of water in every manhole—it depends very much on the situation of the ducts—and if there is a breakdown those ducts can sometimes be bailed out for several days before it is possible to get into them. Mr. Vernier.

Mr. Howell mentioned that a tile of the watershed type was an advantage with crowbars. It seems to me that that depends on what angle the crowbar gets to the tile. If it happens to get square on to the watershed surface it is a distinct disadvantage. With regard to making a longitudinal channel to allow the pitch to run, I do not know whether that is quite an advantage. The method I prefer is to fill the troughs up in two or three pourings, with intervals for cooling and shrinking, and then to pour surplus pitch on the surface of the troughing; then lay the tiles a few inches in front of the space where they are going to rest finally, and drag back the pitch with it which gets between the tiles and seals the joints. I take it that what is intended in this case is that the tiles should be put down first, and then pitch poured in at an open place, which would flow along under them. I do not myself approve of this method, as it is much more likely to leave cavities. Then Mr. Howell

Mr. Vernier. rather suggested he would not lay armoured cables in water-logged districts. We are doing it, and a little later on perhaps we may be able to give him the results. At any rate, we have no hesitation in doing it, not with that special waterproof covering. I may say we do not claim that these coverings are anything like as good as we should like them to be. We certainly are putting pressure on the cable-makers almost every few months to give us something better. With regard to the fact that there are some better coverings, I happen to know of them privately, but I could not describe them at the moment. Mr. Howell's remarks as to hob-nailed boots rather strengthens my dislike of the solid system. It is due to the fact that it is necessary to use unskilled, or practically unskilled labour, and carry out the work under all conditions of weather. There is nothing more disappointing than when a length of cable has just been drawn into the trench, to get a heavy storm come along and simply drown one out. The sides of the trench fall in, and all sorts of things happen which make good work almost impossible. Mr. Howell also spoke about laying it in 10 or 12 ft. at a time. If one could afford to do it in that way I have no doubt a very good job could be made of it; but the paper deals with work on a very large scale, and it is nothing unusual to open a quarter of a mile and do that length at once. With armoured cable, it can be dropped into the trench with the certainty that it is going to be a good job. I am glad to hear that Mr. Trotter agrees with the system of armoured cables and creosoted planking, and also that he supports my view of the 2-in. plank.

Mr. Stedman made some mention of the problems involved in running cables across rivers and docks. This is rather special, and I did not intend to deal with special work in this paper. In the small amount of work I have done in this connection, apart from low-tension work, I have used the ordinary type of lead sheathed and armoured cable for this. I do not think that there is any special difficulty to contend with, the chief trouble being the picking up of cables by anchors. With regard to the potential difference sometimes found between rails and lead-covered cables, I think this is due to the rails not being earthed. Railway lines may be fairly well insulated by the sleepers for long distances, and yet be in contact with earth at some distant point, and a test between cables and rails frequently only results in obtaining the difference of potential between two earth-points some distance apart. I remember a case where there was a voltage between a cable sheath and some colliery rails amounting to 1½ volts. Some of my Post Office friends tell me there is a difference of potential amounting to a good many volts between distant towns in this district, which gives them trouble in connection with their telegraph circuits. It is, again, very probable that in some cases the cable and rails form a couple owing to their being laid in ashes in which there is some active chemical. In those cases where the polarity reverses, this is undoubtedly due to leakage currents emanat-

ing from some source of electric supply, and it is at times quite extraordinary how such leakage currents are met with miles away from any known source of electric supply. To distinguish between Trinidad bitumen and pitch is quite easy to any one who is familiar with both, as the pitch presents a different surface and is more easily broken. The usual proportion of oil which we use in pitch is one part of oil to seven of pitch in liquid form. This is best determined by experiment with the particular quality of pitch used, as this may vary. Mr. Vernier.

Mr. Vesey Brown made some remarks with regard to switching on 19 miles of 20,000-volt cable. Although the matter of switching is not in my hands, one end of the cable being in another company's area of supply, I do not know of any special devices being used on that cable. This length was switched in regularly direct on the system for over a year in this way. I say for a year, because it has recently been shortened by a new sub-station introduced to supply a consumer, which reduces its length to 16½ miles. Since then electrolytic arresters have been installed, as the contractors, who have to maintain it, have suspicions of surges; but so far as my knowledge goes these have never operated. This particular cable, I may say, forms part of a continuous length of 20,000-volt cable 37 miles long, connecting up two large power stations running in parallel. This point about doing without charging devices seems to be one on which there appears to remain a good deal of unnecessary doubt. Several speakers referred to it in the discussion on Mr. Patchell's paper in 1905, and several had evidently installed such apparatus and subsequently found it unnecessary, in one case quite accidentally. The power companies in this district have never attempted to put in charging devices, and have always switched on without them. [Mr. VESEY BROWN: Is this always done on closed circuits?—Mr. P. V. HUNTER: It is always done on open circuits, and I have never known of surges occurring due to switching-in.] Theoretically, and with a sine wave, the pressure rise on switching-in should not exceed double the normal; but Dr. Steinmetz and others point out that in the complex conditions of a large power network this figure may be greatly exceeded (possibly up to four times). Even so, paper-insulated cables will stand this and considerably more quite easily for the extremely short time during which the surge lasts—provided, of course, that there is no resonance between the surge frequency and the system frequency or its harmonics.

In reply to Mr. Hunt, I have not observed the effect of switching-in with an oscillograph, but Mr. Patchell's paper * gives a number of oscillograph curves for the switching-on of various combinations of feeders and in only one or two cases is there any approach to a rise of pressure of twice the normal, while it should be noted that the switching in these experiments was done between brass contracts in air, which are much more liable to produce a rise of pressure than modern oil-switches. Further evidence is given in Mr. Duddell's contribution

* *Proceedings of the Institution of Electrical Engineers*, vol. 36, p. 104, 1906.

Mr. Vernier. to the discussion * on the same paper, where the rise observed in switching-on open-circuited rubber cables did not exceed 2·25 times normal pressure even with a very bad wave-form. It is of special interest to notice that in switching-on the same cables with a transformer on open circuit, connected to them at the far end, the pressure rise was increased to 2·7 times the normal pressure, so that this method appears to defeat its own object.

With reference to Mr. Vesey Brown's suggestion that it might be better to use cable-charging gear and reduce the cost of insulation instead of providing cables with such great factors of safety, I should mention that it is only usual to provide insulation on E.H.T. cables which will stand the normal working pressure continuously with a factor of safety of about 3 or 4; but the physical properties of paper-insulated cables are such that the factor of safety for a cable so designed is of the order of ten to twenty for such transient phenomena as switching-on surges. It takes time to break down insulation, and a very good illustration of this is given by Dr. Steinmetz, which may be of interest. He points out that the sparking distance in air for a certain voltage varies very considerably with the time of application and gives the following figures:—

Voltage	35,000 volts.
If continuously applied the maximum sparking distance equals	2·00 in.
If applied for 0·005 second the maximum sparking distance equals	1·33 „
If applied for 0·002 second the maximum sparking distance equals	0·75 „
If applied for 0·0005 second the maximum sparking distance equals	0·25 „

With air, ionisation no doubt takes place with the longer times of application of pressure, but similar results are obtained with solid insulations. Such figures as those given above will probably account for the somewhat erratic operation of horn-gap arresters so frequently met with, the proper setting of which is usually a most difficult matter in order to ensure that they will only operate when required to do so and will then do so with certainty. As an example of what 20,000-volt cables will stand, the following are some of the tests which such cables have passed satisfactorily:—

100,000 volts for 5 minutes at ordinary temperature.
50,000 volts for 24 hours at ordinary temperature.
90,000 volts for 2 minutes at 156° F.
30,000 volts for 5 hours at 156° F.

As to the explanation why E.H.T. cables break down, I am inclined

* *Proceedings of the Institution of Electrical Engineers*, vol. 36, p. 139, 1906.

to agree with Mr. Hunter that this is a question of heating by dielectric hysteresis. Mr. Vernier.

Dr. Thornton's contribution on this point is exceedingly interesting, especially that part of it relating to the creep of hysteresis, which is new to me. Hochstädter * has published the result of some investigations on the dielectric properties of modern high-tension cables, in which the dielectric loss is shown to diminish rapidly between temperatures of 10° C. and 40° C., after which it increases fairly rapidly. This seems to me a somewhat unexpected result, and one which I think requires further elucidation. Whatever the actual cause of breakdown may be, there is no doubt that cables break down more readily under high temperatures. This point is not often realised, and cable tests should always be specified to be taken at the highest temperature at which the cables will have to run, as this condition is much the most severe which they will have to meet in practice. I have dealt with this matter somewhat at length, as it is certainly a matter of very great surprise to me to learn from Mr. Clothier's remark that switchgear manufacturers are still called upon to provide cable-charging devices at the present time. This, in my opinion, is a needless waste of money, and it is scarcely necessary to mention that the satisfactory operation of a large power system like that of the North East Coast Power Companies' would be seriously interfered with if such devices had to be used, to say nothing of the extra complication of switchgear. I may add that I have never met with a case of a breakdown of a cable due to switching-on at full voltage, although throughout the above companies' 6,000-volt system, all roller spark-gaps and other like protective devices have been dispensed with for several years past. They are only, at present, retained on the 20,000-volt cables to meet the requirements of the contractors who are responsible for the maintenance of the cables. Then again, it is a matter of daily routine to switch on 6,000-and 11,000-volt overhead lines containing long lengths of underground cable in series direct on to the system without any charging gear or protective devices of any kind; and there has never been a breakdown, although the cables are of the standard design for the particular voltage. I suppose those engineers who still use charging gear would consider this procedure absolutely reckless. I certainly agree with Mr. Vesey Brown that the extra money laid out on a good network is money well spent, for if it is not spent in the first instance it will surely have to be spent several times over afterwards. The fact that the cost of cable work has a tendency to increase has been mentioned. While this is true, it is equally true that the maintenance charges on networks laid down during the past ten years have been greatly reduced. This question of capital cost is certainly not one which can be considered apart from the maintenance charges and the ultimate life of the cables.

I was very much interested in Mr. Robb's description of their Forth Bridge difficulties. I have had similar troubles with cables in steel troughing on walls such as can be seen on the railways in this district.

* *Elektrotechnische Zeitschrift*, vol. 31, p. 467, 1910.

Mr. Vernier. There is one length about 300 yards long which has given considerable trouble at cable joints, but since using expansion joints no further trouble has been experienced. I am glad to hear that Mr. Robb has found bonding the salvation of his system. There is no doubt that bonding is one of the most important requirements of a cable system, and people who neglect it or carry it out without proper care only have themselves to blame for any trouble they have. I also notice that Mr. Robb mentions that petroleum jelly is likely to be of assistance in preventing electrolysis, but I do not see how that can very well be, as the iron pipe and cable when well bonded together can be looked upon as one metallic mass, and, of course, corrosion will start outside although it may eventually reach to the cable.

In reply to Mr. Sloan on the fixing of expansion joints, it is usual to provide that the joints allow for a certain movement which it is considered is not likely to be exceeded. Each joint takes up a certain amount, so that the 4 ft. 6 in. movement, or whatever it may be, is spread over a number of joints. If the joints, however, were being put in for overrunning alone and there was no suspicion of subsidence or earth movements, it would be an advantage to take account of the temperature in setting the joints. This can readily be done, as with a particular expansion fitting the total movement for which it is designed can be split into any proportion of expansion and contraction allowance. Thus, with a 6-in. movement fitting this can be divided into 3 in. expansion and 3 in. contraction, or 5 in. expansion and 1 in. contraction, and so on. I should, however, mention that although the expansion of the conductor may be 4 ft. 6 in. in a mile, the movement at the joints is usually much less than this, as, owing to the great friction of the cores inside the cable, a certain amount of this expansion is taken up laterally by slight buckling. This explains why such troubles are not met with to any serious extent until we begin to run cables to high-current densities.

I agree with Mr. Turnbull that wood-troughing is not a good article, and I think that it has seen its best days. At least, I do not think that we shall use it in this district again. The makers of the wood troughing adopt the plan shown in Fig. 3, because it is a simple matter to retain the proper width of the trough by cutting a strip of wood to the exact inside width, and nailing the outside strips to this. In the construction shown in Fig. 4 it is not quite so simple to keep to the exact width, as a piece of wood to form a gauge has to be inserted while the side strips are being nailed on. With regard to pitch running down a hill, I do not know of any case, and I think that pitch should not be used in such a soft condition that it is likely to do this. I am glad to hear that Mr. Turnbull favours armoured cable, and that he has had such satisfactory results. We have some cables in Newcastle which have been laid eleven to twelve years, and are still quite satisfactory. These are laid in sandy soil. With regard to the filling of the strands, there is only one material to fill with in the case of electrical high-tension cables, and that is with the same oil as is used for impregnating the paper, the

whole of the cable being impregnated at one time under vacuum. But perhaps Mr. Turnbull intended to refer to low-tension vulcanised bitumen cables with bitumen-filled strands. This is an excellent thing. One of the greatest troubles with vulcanised bitumen cables is caused by water getting in at a fault, which might run up the strand for several hundred yards. I once had an experience of this sort (in fact, I have had several) on a low-tension vulcanised bitumen cable, through water getting in at a negative fault and running down a hill 200 to 300 yards. I had the cable cut at the bottom of the hill and slipped on a rubber tube about 1 in. in diameter, sealed up at the end, and left it alive about a month; at the end of this time there was about a foot of water in the tube. I then re-insulated all the service joints on the run. This cable has now been running for about eight years, and since that time has given no trouble. Mr. Vernier.

Mr. Hunt asked about proprietary soldering fluxes. I have had several analysed, and I do not know of any of these soldering fluxes entirely free from acid. I always use resin for soldering cores, but for soldering the braid joints I use a mixture of resin and tallow in equal quantities, and I find this is better than resin alone, because pure resin is apt to clog and dirty the fine braid. With regard to Mr. Hunt's remarks as to whether the breakdowns from surges might not be due to cumulative damage, very careful tests have been carried out by Hochstädter,* with an oscillograph, to determine whether cables had anything in the nature of an elastic limit, and he found that no change took place in the properties of the cables right up to the moment of breakdown.

A number of speakers have mentioned the question of surges, and I am in agreement with Mr. Porter's explanation. It is not always realised what a tremendous amount of energy may be set free in the event of a short circuit on a large power system, particularly if in the neighbourhood of a big power station. While the short circuit lasts, there may be a discharge of several hundred thousand kilowatts, although the plant capacity may not exceed 50,000 k.w., and I have known the case of a large system where a severe short circuit on a cable has lowered the voltage from 6,000 to 5,000 volts momentarily throughout the system. In this connection the value of an instantaneous system of balanced protective gear such as the Merz-Price cannot be overestimated, as this will usually open the switches before the short circuit breaks itself; and as these switches are now invariably of the oil type, the current is broken at or near zero-point, thus preventing excessive rises of pressure, shock to the system, and interference with the supply.

Mr. Morton has also referred to this system of protection in another connection. This acts so quickly that it is sometimes a great nuisance to the mains people, but it is just that feature of its operation which has proved of such importance to the consumer. It is in many cases necessary to put a pressure test on the cable to break down the fault

* *Elektrotechnische Zeitschrift*, vol. 31, p. 467, 1910.

Mr. Vernier. sufficiently for localising tests to be put on. On the other hand, it is of very great advantage on a large system, as the faulty feeder is immediately isolated, and it is not therefore necessary to sectionalise a number of interconnected cables in order to find the faulty one, as so frequently happens with other systems of protective gear.

In reply to Mr. Hunt, I have already remarked that paper cables have a very large factor of safety for a rise of pressure lasting but a short period, and I think it is quite within reason for a 20,000-volt cable to withstand momentarily from 200,000 to 300,000 volts, or even more. I know of cases where 6,000-volt cables have stood up satisfactorily to surge pressures of 100,000 or 150,000, as evidenced by sparking which took place across large distances on switchgear to which they were connected. Several speakers have given their views upon the methods they would adopt to guard against electrolysis, and all, with one exception, are in favour of earthing the lead. Mr. Dawson is the exception, and although the method he deals with in his contribution is outside the scope of the paper, as the Board of Trade regulations do not admit of its use on high-pressure cables, I feel that I must utter a note of warning to those who might be disposed to consider the adoption of such a method. The danger in breaking-up the lead sheath into sections at joints, leaving aside the question of its efficacy as a prevention of stray current electrolysis, is that on low-tension networks consisting of single core or multicore cables, which must of necessity be heavily fused, faults occurring on one pole may render the lead alive without blowing the fuses and cause what I term "live-lead" electrolysis as distinct from "stray-current" electrolysis. This may speedily destroy a considerable amount of cable and also pipes in the vicinity, according to the polarity of the lead sheath to earth. Mr. Dawson may attribute his immunity from this sort of trouble to the fact that his cables are of the concentric type, which, when they break down, generally develop into a "dead short circuit" immediately. I have come across several serious cases of this "live-lead" electrolysis, which, since the voltage to earth may be considerable as compared with that of stray currents, causes very rapid corrosion—in fact, a considerable amount of cable can be ruined in this way in the course of two or three days. There is also great danger of electrolysis taking place from small leakages over cable ends at joint-boxes and on switchgear.

Mr. Dawson further discusses the question of current leaking from cable sheaths on to water pipes, assuming the neutral wire of the supply is connected to these pipes. I think it is extremely unwise to connect the neutral wire to water pipes at the generating station, as this will certainly cause electrolysis on the pipes and create the sort of leakage paths which he has discussed at length. In earthing the lead sheaths of a lead-covered network at the power station, care should always be taken not to earth to the same earth-plate as is used for earthing the neutral wire, and an entirely separate earth-plate should always be put down for this purpose at some distance from it. Lead bonds I would most strongly object to. All bonds should, in my opinion, be of

copper, of equivalent conductivity to the lead sheath, and never less than 0·05 sq. in. in sectional area, as otherwise we can never be sure that they have not gone up into smoke in the manner described. Mr. Vernier.

I agree with Messrs. Beaver and Hunter that with most woods, when used for bridges and bushes, the corrosion of the lead sheath is chiefly due to the acid electrolyte facilitating electrolysis. This is not so with all woods, however, as oak and possibly other woods have a considerable purely chemical action on lead and will corrode this through very rapidly in the presence of air and moisture, the action in the case of oak being similar to the Dutch process of manufacturing white lead.

Messrs. Burrows and Hogg's experience with expansion joints bears out very well the similar successful results I have obtained with such joints. Expansion joints for cables are, of course, no new thing, and I believe were first used by Mr. Ferranti on the Deptford mains laid twenty-two years ago, which were constructed of solid copper tubes. The chief object in the design of the joint described in the paper was to obtain a joint which could be used without any radical alteration of the usual designs of joints and joint-boxes in ordinary use, up to and including the highest voltages, and which could be so cheaply made as to encourage its universal adoption. The question has been asked as to the need of expansion fittings at every joint. It is certainly most important that all joints in the affected area should be of the expansion type, as otherwise intermediate non-expansion joints will continue to give trouble. It is in many cases most difficult to define where an affected area begins and where it ends, or to decide upon what is likely to prove an affected area at the time of laying the cable. For this reason, as well as for overrunning possibilities, the extra cost of putting in expansion joints throughout being so slight, it is well worth doing this in the first instance. I know one length of about 1 mile of cable where as much has been spent on subsidence breakdowns in less than three years previous to the use of expansion joints as would have paid for inserting expansion joints in the first instance on over 50 miles of the same cable system. Several speakers asked for further information on the use of such joints. In reply to Mr. Beaver, very few breakdowns have taken place in the cables themselves as compared with breakdowns at joints. When such breakdowns have taken place, it was usually after the nearest joint had buckled considerably, and thus more resistance to movement came upon the cable, generally at a bend. My experience has been that movement of the conductors is always transmitted to the nearest joints, which, as they are weaker than the cable, either buckle or break. Expansion due to heating is, of course, very much more easily transmitted, as the expansion takes place uniformly along the cable and the movement becomes cumulative up to the joints at each side. In connection with subsidences, it is necessary to consider plain lead-covered cables laid on the solid system and armoured cables laid direct in the ground separately. With solid systems both

Mr. Vernier. tension and compression troubles may be experienced. Compression is usually caused by a moving stratum of earth which grips the sockets of the troughing and drags the lead sheath, paper insulation, and conductors along with it up to some point where movement ceases. With armoured cables laid direct in the ground, I have never experienced a case of compression trouble. This appears to be due to the fact that moving soil cannot grip this type of cable so tightly, also to the fact that any compression on the spiral armouring tends to make it buckle and open out and so lose its grip on the lead sheath. Wire-armoured cables, in reply to Mr. Morton, are of great assistance in diminishing troubles from subsidence, but they do not avoid tension troubles, as the spiral armouring can stretch considerably, on a long length, like a rope, although not to the same extent as plain-covered cable. Slack cable at joint-boxes or elsewhere is quite ineffective, unless the subsidence is so close to it that the slack can draw out. The lead sheath of cables without slack rarely shows any appreciable movement at cable glands, and out of some fifty cases, all on solid systems, I have only found one case where the lead was damaged due to external damage by the tiles, but all the other cases only showed slight corrugations in cases of compression. Some compression movement on the solid system is, of course, taken up at each trough joint, as the ends of the troughs are seldom butted up close to one another.

In reply to Mr. Vesey Brown, the thickness of the tubes used for the expansion fittings varies from 1/16 in. to 3/32 in., while the flexible braids are designed from the point of view of current-carrying capacity. The tube does nothing more than maintain the ends of the conductors in alignment and, as it is quite a loose fit on them, it does not need to have any great strength. In reply to Mr. Addison, the movement of the conductors against one another is not more likely to reduce the dielectric strength than the constant movement which takes place with all cables due to heating and cooling under changes of load. Further, the bending the cable receives in the process of laying is usually much more severe, and it is known quite well what cables will stand after the usual severe bending tests.

Mr. Bridges has dealt fully with the drawn-in system, and I agree with him that this system requires a good deal more consideration than it usually receives. Coffin-shaped manholes are best for multiple-way ducts, as in this case the pipes cannot be splayed out. I think a better design of manhole than that shown in Fig. 2, although a little more expensive, is, instead of splaying out the pipes, to bring them one to each side of a brick wall dividing the manhole longitudinally in the middle. This gives practically two separate manholes, and any damage from the cables on one side of the wall cannot be transmitted to those on the other; also a perfectly straight lead into the pipes can be obtained for drawing in without using covers with very large openings.

The use of taped and braided cable for drawn-in work has been criticised by Mr. Morton and other speakers. The type of braiding I had in mind is similar to the protective covering described in the

paper in connection with armoured cables, or with the more recent improvements of these coverings. I agree that in severe cases of electrolysis it may not afford any great protection, and in such cases the conditions should be remedied, but I have in mind cases of extremely slow corrosion due to electrolysis in pipes which are practically dry. I have seen such slow electrolysis on cables in use eight years and which are still running. I think in cases of this kind a taped and braided covering would prolong the life of the cables, while against chemical action it would, I think, be an even greater protection. With regard to the use of braided cable for laying solid, there is no doubt that filling compositions adhere very closely to such braidings, even if damp. Those used to laying vulcanised bitumen cables solid can bear this out, and it is due to the impregnating compounds in the braidings, which exude when the hot filling composition is poured on. I have no doubt that a very great improvement could be obtained with plain lead-covered cables on the solid system if the cables were tarred or coated with a similar composition by the makers before laying. Mr. Vernier.

The joint Mr. Mitchell has produced is practically on the lines shown in Fig. 15 of the paper and should be an improvement on tape-insulated joints. I prefer, however, to allow the compound to flow between the separate cores as far as possible, so as to increase the leakage surface. The chief reason why conduits are laid in concrete is for the mechanical protection this affords against external damage. It also renders the system, if properly laid, much less accessible to external moisture, due to water getting in at the joints of the pipes or conduits. The use of concrete further makes a very rigid system not so likely to be affected by subsidence. The accessibility of the draw-in system, claimed as an advantage, is often but an excuse for people who are poor hands at fault locating, as by opening a few joints the fault does not require locating closer than a few hundred yards. With proper tests a fault on a buried system, even of several miles, can be repaired as easily, while the cost of repair is usually a mere fraction of what it would be on a draw-in system. Buried systems do not require periodical inspection, and this saving on a large system is quite an important matter. As to protecting cables on the solid system against external moisture, the question is an important one, and while I think the system is not sufficiently practical for work on a large scale, had I been discussing distribution work in towns my views would have been somewhat modified. It depends greatly on the facilities available for carrying out the work properly and the conditions which have to be met, but I think that in any case with this system too much is left in the hands of men who in the ordinary way are recruited from the ranks of unskilled labour.

Mr. Macleod has referred briefly to the expansion of cables. In regard to the expansion of cables when running at high-current densities, although the conductors do expand 4 ft. 6 in. per mile, the cable itself does not expand so much. There is a limit where lateral displacement cannot take place any further and where it comes on the

Mr. Vernier. joint. If it was not for that, trouble from heating of cables would be much more frequent. It is only when high-current densities are reached that there is need to fear. With regard to the use of expansion bends, I do not think, unless the subsidence takes place quite close to where the bend is located, that it can be provided against in that way, because the cable cannot be got to pull through the ground, but it stretches at the point where the subsidence takes place, and the conductors draw right through the lead sheath to the nearest joint and pull it out. That has been my experience. If it is wished to provide against a subsidence and it is known where that is, a bend may be put at each side and the trouble got over in that way; but the fact should not be lost sight of that it is not possible to bend or straighten out a cable without giving unequal displacement to the several cores. The longitudinal movement at joints is much smaller than the sag of the cable at the subsidence, and it is well known from overhead line work, for instance, that the increased length of wire in a span of 100 yards for an increase of sag from 1 ft. to 5 ft. is only 2 in. This indicates very roughly one reason why comparatively large subsidence movements can be dealt with by smaller limits of movement at joints.

Mr. Lackie referred to the importance of the mains in an electrical undertaking, and although mains' engineers are, I agree, relatively fewer in number, the men engaged in this work might, I think, give us a little more of the results of their experience, because mains represent such a large proportion of the capital of our undertaking, and, what is more important still, they are out of sight. More frequent ventilation of ideas on the subject would in many cases save a lot of money. What is required is dissemination of knowledge. Cable-makers, as might be expected, kept these matters to themselves in the old days, and we had to go to them or suffer from lack of experience. Faults in manufacture are rare, and although it is true, as Mr. Lackie says, that it is not always easy to tell the exact cause of a fault, cable faults themselves are exceedingly rare.

Mr. Tidd practically replied to the next point. I refer to the fact that in a multiple-way duct there is only one wall of earthenware. With a flush joint an inch of concrete, say, can be got in as a minimum, and that will prevent a considerable amount of interference between ducts. With an ordinary socket pipe it is obligatory to put in a greater thickness. With regard to Haskinised wood, I have never had any experience of it. I should like to obtain some particulars of the experience obtained. With reference to whinstone dust, Professor Baily mentioned one point I intended to raise, viz., the absorption of moisture. I have, however, no experience in regard to that matter. It is possibly quite all right, but it wants consideration. The experiment recorded by him is of particular interest, as it may be recollected that a few years ago a good deal of correspondence took place in the electrical press on a method of laying cable in sand mixed with liquid tar instead of the usual pitch or bitumen. Mr. Lackie also mentioned that the heat of pitch is much lower than that of bitumen. I referred to that in

Mr. Vernier.

my paper as a point in favour of bitumen, as it does not get chilled against a lead surface and therefore adheres better. With regard to methods of protection, one of the London Companies uses iron plates laid on wood planks, and although it would be possible to go through the iron plate alone it is almost impossible to go through it if it is placed on a resilient surface like a piece of wood. If iron bridges are used, I think the lead should be earthed at intervals, otherwise a number of points in imperfect contact with the lead sheath are obtained, and since these may be of varying resistance to earth, they would lead to trouble. In connection with filling up strands, that is more important in low-tension work. Of course, all high-tension cables have the strands filled up in the impregnation of the cable, which is done under a vacuum, but with vulcanised bitumen cable, if the strands are not filled up, water may run up a considerable distance.

Mr. Tidd has given us some samples of fibre ducts. I am quite favourably disposed towards these. The amount of it used in this country, while on the increase, is nothing compared to the amount which has been used in America. With regard to a solid system with these ducts, I should think one difficulty would be to get the top part quite full owing to its circular form.

In reply to Professor Baily, I have no experience of concrete troughs and I do not know if they are still on the market. I have had no experience of glass wool, but ordinary asbestos is a very bad thing to use on cables; it absorbs moisture so readily. I do not know of any trouble due to the lead not going back, as Professor Baily mentioned. I know that this trouble has occurred in other directions, but I have never met it in connection with cables.

Mr. Mavor also spoke of the perfection to which cable manufacture has been brought. I think we can have every confidence in the products of our leading cable-makers. Personally I have never had any difficulty, and while it may seem a rash practice I may say that we have not found it necessary for many years even to put an insulation test on cables until they are laid and completed ready for pressure testing.

The President.

The PRESIDENT: I now ask you to give a hearty vote of thanks to the author for his paper.

The resolution was carried by acclamation.

Proceedings of the Five Hundred and Twenty-first Ordinary General Meeting of the Institution of Electrical Engineers, held on Thursday, April 27, 1911—Mr. W. Duddell, F.R.S., Vice-President, in the chair.

The minutes of the Ordinary General Meeting, held on April 6, 1911, were taken as read, and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Hall.

The following list of transfers was announced as having been approved by the Council:—

TRANSFERS.

From the class of Associate Members to that of Members:—

Herbert J. Hawkins.

From the class of Students to that of Associates:—

William Meggatt Dempster.	Alan E. D. Kennard.
Surendranath Ghosh.	James G. Stewart.
Trevor Hedberg.	Aubrey Bertram Stratford.

George Tingley.

Messrs. S. Rudd and W. Howard Tasker were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been elected:—

ELECTIONS.

As Member.

Herbert Brandon White.

As Associate Members.

Reginald Ayton.	Christopher Huntington Hird.
John Hume Bell.	William Hodson.
William Bowen.	Robert Sanderson Hubbell.
George Bennett Burrows.	Edward Hughes.
John Carnie.	Andrew Hutcheson.
Walter Wilson B. Crompton.	Shamanna Bellary Iyengar.
Ernest Philip Elwin.	Alfred Walter Maley.
Edmund Henkhe.	Francis Morley Ward.
Willoughby John Henry.	Richard Henry Wilkinson.

As Associate.

Harold Charles Townsend.

As Students.

Albert Harry Barrett.
Ernest Flint Boynton.
Duncan Donald Campbell.
Stanley Allan B. Campbell.
Kshitish Chaudra Mittra.
Edgar Potter.
Reginald Walter Shackell.

Donations to the *Library* were announced as having been received since the last meeting from P. R. Allen, L. Birks, O. Bonazzi, S. K. Broadfoot, The Bureau of Standards, Washington, A. Constable & Co., L. Hansen, J. H. Johnson, Lady Kelvin, Sir J. Larmor, The Physikalische Technische Reichsanstalt; to the *Museum* from Brackenbury Bayly; to the *Building Fund* from W. A. Del Mar, G. M. Robertson, N. Tesla; and to the *Benevolent Fund* from L. Birks, and S. Sharp, to whom the thanks of the meeting were duly accorded.

The Chairman then read the following nominations made by the Council for the election of the Council and officers for the year 1911–12:—

MEMBERS NOMINATED BY THE COUNCIL FOR OFFICE, 1911–12.

As President.

New Nomination — S. Z. de Ferranti.

As Vice-Presidents.

Remaining in Office — W. Duddell, F.R.S.; W. H. Patchell.

New Nominations — Major W. A. J. O'Meara, C.M.G.; J. F. C. Snell.

As Honorary Treasurer.

For Re-election — Robert Hammond.

As Members of Council.

Remaining in Office —
W. W. Cook.
H. Dickinson.
G. K. B. Elphinstone.
W. Judd.
P. V. McMahon.
R. K. Morcom.
W. M. Morrison.
S. L. Pearce.
H. Faraday Proctor.
C. H. Wordingham.

New Nominations
- J. S. HIGHFIELD.
- H. HIRST.
- B. M. JENKIN.
- J. E. KINGSBURY.
- C. P. SPARKS.

As Associate Member of Council.

Remaining in Office
- E. RUSSELL CLARKE.
- S. MORSE.

New Nomination H. E. WIMPERIS.

The following paper, "Battery Economics and Battery Discharge Arrangements," by Mr. A. M. Taylor (see page 393), was then read and discussed.

BATTERY ECONOMICS AND BATTERY DISCHARGE ARRANGEMENTS.

By A. M. TAYLOR, Member.

(*Paper received November* 9, 1910. *Read before the* INSTITUTION *April* 27, 1911, *and before the* BIRMINGHAM LOCAL SECTION *April* 26, 1911.)

SUMMARY.

The author deals with the question of rapid discharge rates and their effect on the total ampere-hour capacities and terminal E.M.F.'s of batteries.

Methods of discharge by regulating cells alone, as employed on the Continent, are discussed, and their disadvantages pointed out.

Methods of discharge by boosters, as at present practised in this country, are also discussed, and suggestions are offered for materially diminishing the cost and inefficiency of these methods.

Batteries are next considered as a pure standby to steam plant, and the arrangements employed in New York and other towns for this purpose are described.

The economy of employing batteries for extensions in alternating-current sub-stations distributing with direct current, instead of additional steam plant at the main station, is discussed.

The question of the use of rectifiers for the purpose of charging batteries off E.H.T. alternating-current mains, for use on the premises of large consumers, is also considered.

A note is added on the employment of batteries as a means of improving the power factor in alternating-current distribution.

A further section deals with an alternative proposal to batteries as a means of dealing with peak loads, put forward by H. G. Stott of America, employing exhaust turbo-generators and boilers with enlarged fire-grates.

Some particulars of recent Continental and American battery installations are given in an appendix.

INTRODUCTION.

It is now some two and a half years since the author read a paper before the Municipal Electrical Association at Nottingham on the subject of accumulators for peak loads, and as the correctness of the principles then enunciated has been in some measure verified, and the engineers of some large towns are considering the question, it is hoped that some notes as to improved methods of arranging

batteries and boosters, as well as an indication of the conditions which are most favourable to the introduction of accumulators for this purpose, may be acceptable. Since that paper was written the circumstances of the case have somewhat altered, and the author is now able to point with some satisfaction to the large battery installed by Mr. Pearce at Manchester, on which results of the most gratifying nature are being obtained, the coal bill being reduced by some 25 per cent. apart from large savings in the fixed charges.

Rapid Discharge Rates.

As the whole question of the utilisation of accumulators for rapid discharge rates is very intimately bound up with the final cell voltages on discharge, as well as with the number of ampere-hours that can be taken out of the battery, it becomes of considerable interest to know what is the maximum rate of discharge that one

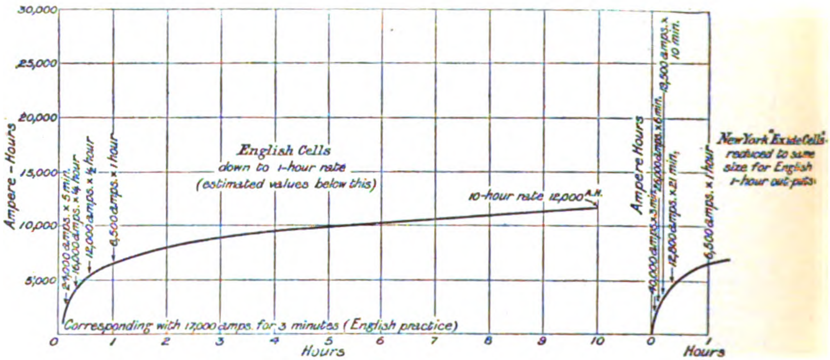


FIG. 1.

may take out of a given battery in an emergency. The author knows of no results published in this country dealing with discharges at considerably higher values than the 1-hour rate, and though he is, by the courtesy of the Tudor Accumulator Company, able to attach to this paper some curves representing their recommendations in this direction, he still feels that it may be of interest, and also help in stimulating a discussion on this paper, to base his conclusions upon results actually obtained with Exide cells in New York, in which the discharge is carried to a considerably further degree than has hitherto obtained in English practice.

In Fig. 1 will be found a curve connecting ampere-hours with hours of discharge, the values of which between the 10-hour rate and the 1-hour rate are taken from English practice, and those between the 1-hour rate and the 5-minute rate are estimated values which, however, are very closely confirmed by the values obtained with the Exide cells which are given on the right-hand side of Fig. 1. In Fig. 2 are given

the initial and final discharge voltages for different periods of discharge. Here, again, the English figures below the 1-hour rate are merely estimated, but it will be seen that they follow the same tendency as the actual values obtained on the Exide cells. In Fig. 3 a series of curves is given, showing the result that might be obtained on a cell of a given type and size if charged and discharged at different rates. The values of the terminal voltage on discharges below the 1-hour

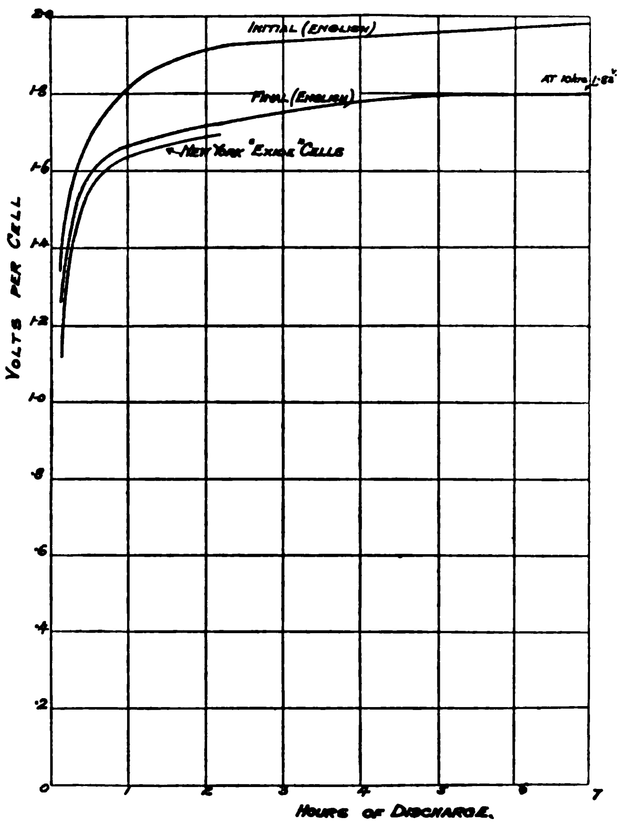


FIG. 2.

rate are calculated to agree with the curve given in Fig. 2. On the same sheet are shown the performances of the Tudor cells under similar conditions.

REGULATING CELLS.

The method of discharging large batteries by means of regulating cells has been employed on a considerable scale both in

America and on the Continent, whereas in Great Britain, owing no doubt to J. S. Highfield's activities in 1901, the tendency has rather been to employ boosters for the discharge. It is somewhat difficult to bring home to an engineer who is not accustomed to batteries exactly what takes place as regards the distribution of the charge left in the end cells of a battery where regulating cells are employed, and with a view to making this plainer the author has constructed a diagram (Fig. 4) in which a sufficient number of regulating cells is introduced to permit the battery to be discharged if necessary at the 5-minute rate. The diagram, however, primarily shows what happens when the battery is discharged at the 1-hour rate. If it were never intended to use the battery at over the 1-hour rate, only 303 cells would be required, viz., 190 cells in the main battery and 113 regulating cells.

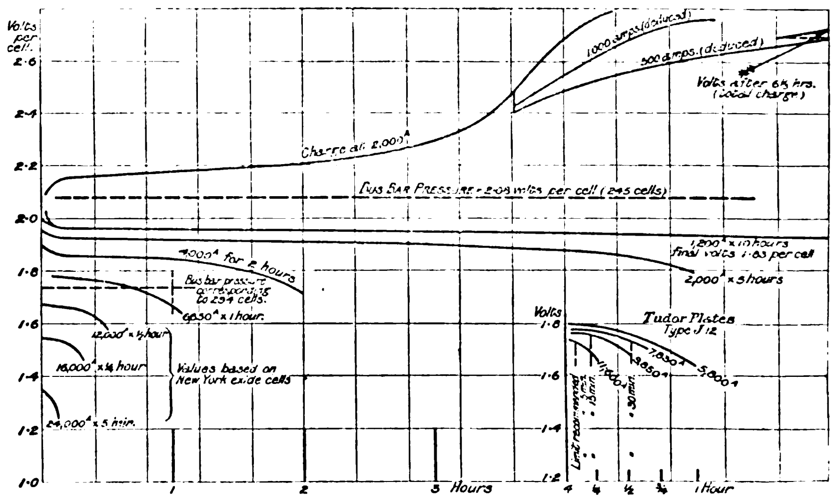


FIG. 3.

It will be noted that the last 57 cells do not become properly charged unless the battery be charged at exceedingly low rates, taking a correspondingly long time, also that some of the cells are practically never discharged. This is accentuated considerably if the full number of cells (365) be installed in order to meet the extremely rapid rate of discharge, and the battery nevertheless be normally only discharged at the 1-hour rate, a larger proportion of the cells being then virtually useless except as a standby. These cells also have to be fitted with regulating switch contacts, and the cost of the regulating switches becomes very considerable, besides the difficulty of maintaining cells in a healthy condition which are hardly ever called upon to give a discharge. It appears to the author that though this method of working batteries is very simple and reliable, yet it has many dis-

advantages, especially where rapid rates of discharge are likely to be required. In Fig. 5 is shown the arrangement of cells that would be

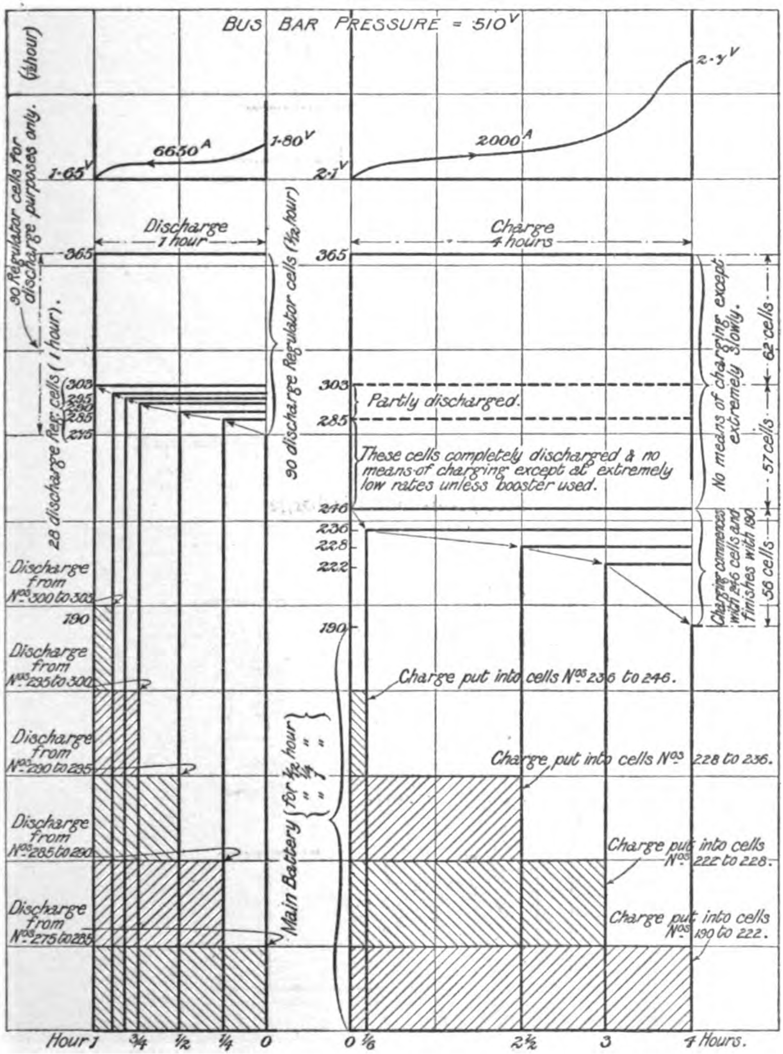
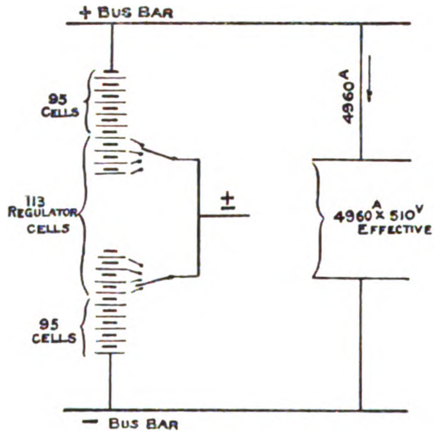


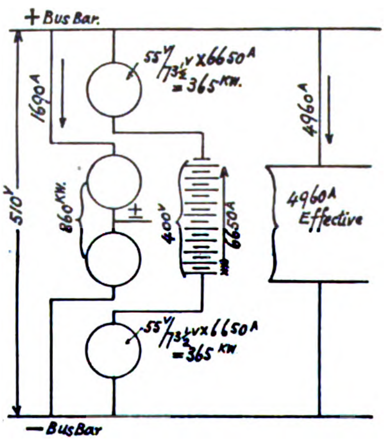
FIG. 4.

required to give an effective discharge of 4,960 amperes at 510 volts for one hour. (This particular value of current is taken for purposes of comparison with those that follow.)



FOR 1/4 HOUR DISCHARGE (10070A) ALLOW 144 REGULATOR CELLS.
1/12 " " (12500A) " 176 " "

FIG. 5.—1-hour Discharge.



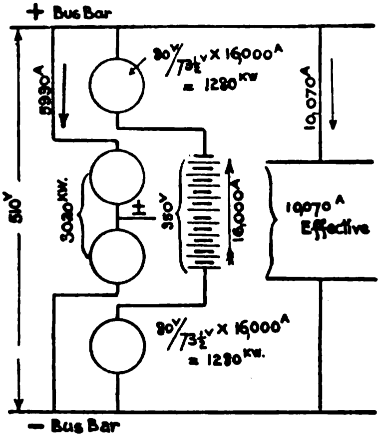
240 CELLS

NOTE:- THE 73½ VOLTS IS FOR THE CHARGE

FIG. 6 (Scheme A).—Ordinary Arrangement. 1-hour Discharge.

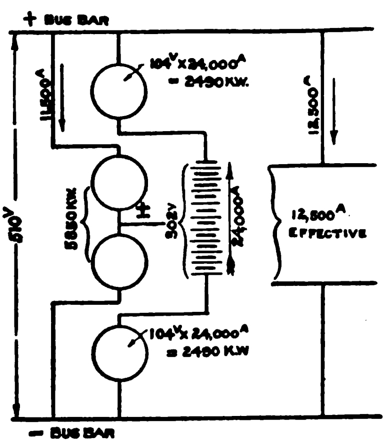
BOOSTERS.

Up to the present time it has been very costly to obtain from boosters the necessary boost to get the discharges which are indi-



240 CELLS.

FIG. 7 (Scheme A).—Ordinary Arrangement. ½-hour Discharge.

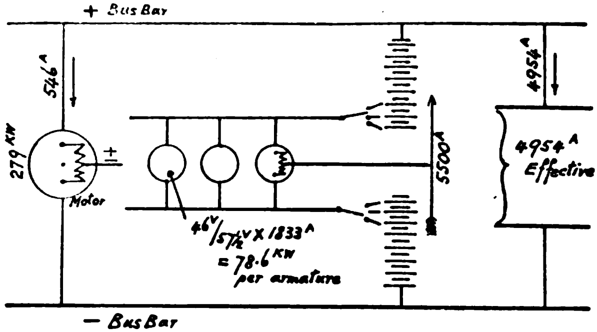


240 CELLS.

FIG. 8 (Scheme A).—Ordinary Arrangement. 5-minute Discharge.

cated in Fig. 1 out of the batteries. The voltage of the boosters has to be increased to such a degree that, combined with the high-current rate, the resulting kilowatt capacity becomes very expensive

to provide for. Virtually this has, in the author's opinion, resulted in an insufficient provision being made in boosters for discharging the battery at emergency rates, and it seems to be considered good enough

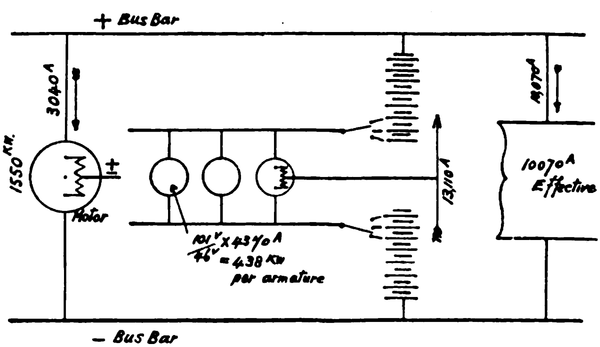


280 CELLS.

NOTE:- THE 57½ VOLTS IS FOR THE CHARGE.

FIG. 9 (Scheme B).—Triple-Series Arrangement with Static Balancers. 1-hour Discharge.

either to throw the battery direct on to the busbars on emergency conditions or to draw upon reserves (as, for instance, at Manchester). This, of course, means either that the batteries will never give the



280 CELLS.

FIG. 10 (Scheme B).—Triple-Series Arrangement with Static Balancers. ½-hour Discharge.

discharge they are capable of giving, or that, in order to obtain this discharge, the busbar pressure at the station must fall tremendously. For example, in Fig. 6 it is shown that the busbar pressure would

have to fall from 510 to 400 volts. In Fig. 7 it would have to fall to 350 volts, and in Fig. 8 to 302 volts, to get the discharges indicated. This is, of course, a serious matter for a central station to face. The author hopes to show that it is practicable to put in boosters to deal with a quarter-hour discharge at a cost not exceeding what is at present spent in obtaining a 1-hour rate of discharge, and that the cost for boosters, in the case of the 1-hour rate, may be reduced to less than half of what is now spent upon them, with an all-round gain in efficiency.

With a view to emphasising the extent to which the cost of the boosters may be reduced by a suitable arrangement of boosters and batteries, the author gives, in some detail, an investigation into a particular case in which it is desired to deliver an effective discharge on to the busbars of 2,530 k.w. (510 volts) for one hour, or 5,140 k.w.

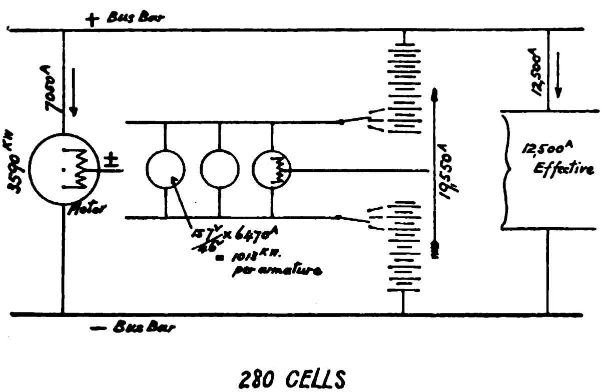


FIG. 11 (Scheme B).—Triple-Series Arrangement with Static Balancers. 5-minute Discharge.

for a quarter of an hour, or 6,370 k.w. for 5 minutes. Three different methods of obtaining this result are shown diagrammatically in Figs. 5, 6, 7, 8, 9, 10, and 11. The two battery charge and discharge curves, given in Figs 12 and 13, respectively indicate the outputs required from the boosters in the case of the arrangements shown in Figs. 6 and 9, the 1-hour rate of discharge being taken for comparison in each case. It will be noted on referring to Fig. 6 that the battery current has to be 1,690 amperes greater than necessary to reproduce the effective line current of 4,960 amperes. In Figs. 7 and 8, particularly the latter, the battery current thus wasted is very considerable. Referring now to Fig. 9, it will be seen that the battery has in this case to supply only 5,500 amperes as against 6,650 amperes in Fig. 6, for the same effective line current, the 1150 amperes thus saved permitting a smaller size of cell to be used. This does not, however, appreciably reduce the cost of the battery itself, as a

rather larger number of cells is required than in Fig. 6. It will be noted, however, that whereas the output of the booster in Fig. 6 is $365 \times 2 = 730$ k.w., it is in Fig. 9 reduced to $78{\cdot}6 \times 3 = 236$ k.w., a saving of nearly 500 k.w. (1-hour rating). This means that, whenever the

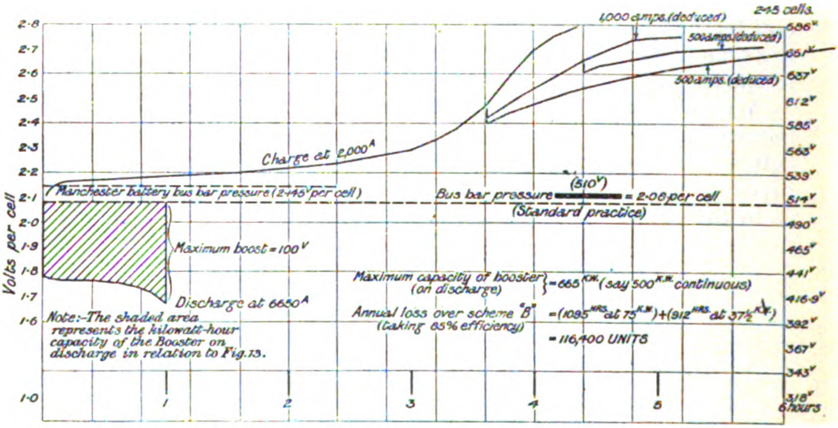


FIG. 12 (Scheme A).—Ordinary Boost Arrangement.

Standard Arrangement of Booster and Battery (245 cells).

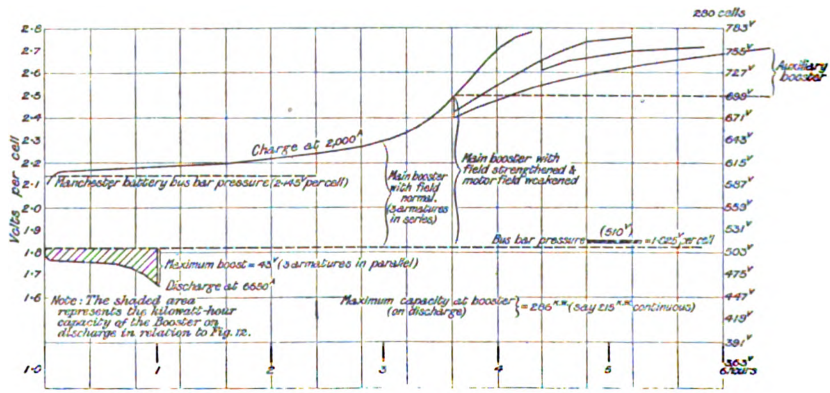


FIG. 13 (Scheme B).—Proposed Boost Arrangement.

Special Arrangement of Booster and Battery (280 cells).

boosters in Fig. 6 are running, an unnecessary amount of machinery, to the extent of some 500 k.w., is being continually turned round, representing a perpetual waste of energy which is of the order of 116,000 units per annum. The two sets of curves in Figs. 12 and 13

show very clearly, by the relative areas of the booster curves on discharge, the above saving.*

A summary of the conditions obtaining in the three different methods above alluded to—viz., regulating cells, ordinary boosters, and "triple series" boosters—will be found in Table A, which also gives an approximate estimate of the cost of the batteries and of the boosters.

In Fig. 14 is shown a diagram of connections for obtaining the "triple series" arrangement of boosters. As shown in the right-hand bottom corner of this figure, a motor can be employed to drive two double-wound booster armatures, each having two commutators, giving four booster armature windings, which can be coupled in series or parallel; the fourth winding, however, would be used as a spare. A preferable arrangement, where cost is not a prime

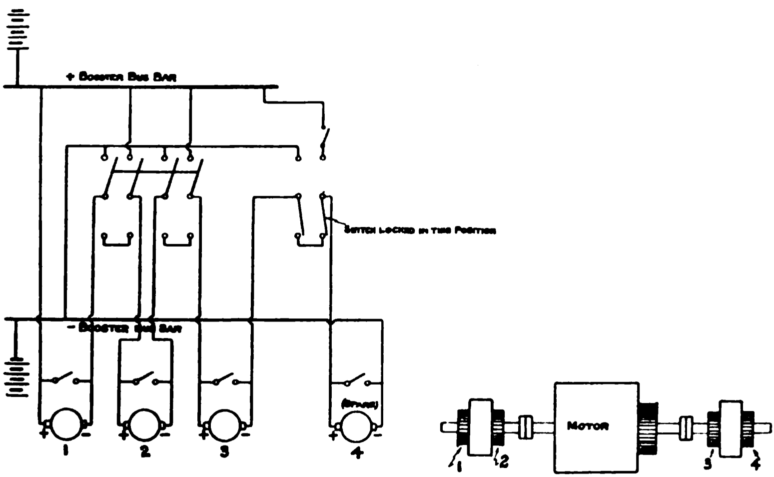


FIG. 14.

consideration, would be to have two separate motors and four single-wound armatures, each under its own field.

In Fig. 15 the author shows an arrangement which it appears to him might with advantage be employed in cases where the battery has to be used with a regular load of known amount daily, and more particularly where the cells can be either charged from traction busbars or preferably where rotary converters of the split-pole type (or of the alternating-current booster type), having a large range in their voltage, are available. Where desired, existing rotary converters can be adapted for this purpose quite easily and at a low cost.

* The curves in Fig. 12 have by mistake been got out for 245 cells instead of 240, and the figures on this curve therefore do not quite agree with those in the table alluded to below, but the difference is unimportant.

TABLE A.

Summary of Figures in Figs. 5 to 11.

No. of Fig. and Description.	Period of Discharge.	(Gross) Kilowatts of Discharge to B B (at 510 Volts).	Effective Kilowatts of Discharge to B. B.	Battery Amperes of Discharge.	Number of Cells.	Number of Regulating Cells.	Booster Discharge in Kilowatts (at Machine).	Motor Current (at 510 Volts).	Effective Line Current.	Final Discharge, E.M.F. per Cell.	Final Charge, E.M.F. per Cell.	Output of Auxiliary Booster (Kilowatts).	Estimated Cost of Battery (alone) per Effective Kilowatt on B B.	Estimated Cost of Main Booster, per Effective Kilowatt on B. B.	Cost of Auxiliary Booster per Effective Kilowatt on B/B.	Total Cost per Effective Kilowatt on B B.	Highfield's * Costs in 1901.
	Hour.												£	Reg. Switches. £	£	£	£
Entirely with regulating cells (Fig. 5)	1	2,530	2,530	4,960	303	113	—	—	4,960	1·67	2·7	—	5·36	1·50	—	6·86	—
	½	5,140	5,140	10,070	332	144	—	—	10,070	1·46	2·7	—	3·18	1·00	—	4·18	—
	1/12	6,370	6,370	12,500	365	176	—	—	12,500	1·26	2·7	—	2·34	0·70	—	3·04	—
Ordinary booster with motor balancer (Figs. 6 to 8	1	3,390	2,530	6,650	240	Nil.	730	1,690	4,960	1·67	2·7	—	5·70	1·44	—	7·14	14
	½	8,150	5,140	16,000	240	Nil.	2,560	5,930	10,070	1·46	2·7	—	2·80	2·08	—	4·88	—
	1/12	12,200	6,370	24,000	240	Nil.	4,980	11,500	12,500	1·26	2·7	—	2·26	2·45	—	4·71	—
Triple series parallel booster with static balancer (Figs. 9 to 11)	1	2,810	2,530	5,500	280	For balancing. 10	236	546	4,954	1·67	2·7	58½	5·49	0·46	0·14	6·11	14
	½	6,700	5,140	13,110	280	10	1,314	3,040	10,070	1·46	2·7	58½	2·71	1·06	0·07	3·84	—
	1/12	9,970	6,370	19,550	280	10	3,039	7,050	12,500	1·26	2·7	58½	2·19	1·49	0·06	3·74	—

* *Journal of the Institution of Electrical Engineers*, vol. 30, p. 1,040, 1901.

In this scheme (C) the number of cells is so chosen that the maximum, or peak, output occurs at such a period of the discharge of the battery that practically no boost is at that time required for the latter (see central point of the 510-volt busbar line of Fig. 15). For, say, one-quarter of an hour on either side of this point the boosters are worked with their armatures in parallel and are thus able to deal easily with the 6,650 amperes. During the earlier and later

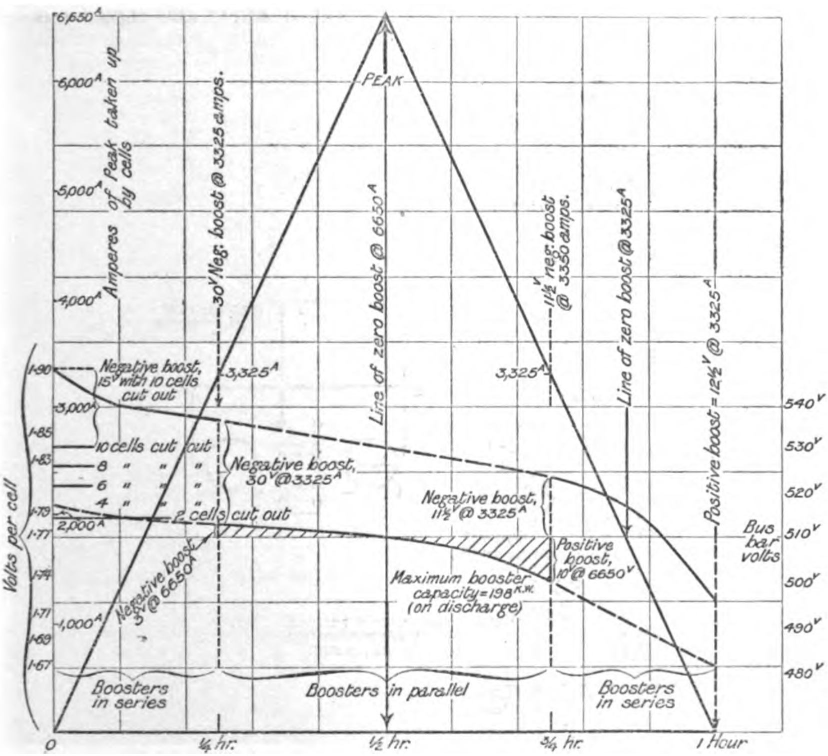


FIG. 15 (Scheme C).—Boost Arrangements for a Special Case.

288 Cells. Busbar Volts = 510 (with maximum number of cells).

portion of the peak, however, the current being then much less, the booster armatures are put in series with each other. A few regulating cells, as indicated, may be employed if desired, and these could be cut out as shown in Fig. 15 should the discharge rate require to be reduced in the early part of the discharge beyond that shown by the curve.

If traction busbars were available, or a rotary converter could be modified to give sufficient voltage range for the charging of the cells (assisted by the battery boosters), the output of the battery boosters

could, in the latter case, be reduced to as small a value as 66½ k.w. (10 volts × 6,650 amperes). If, however, neither a suitable rotary converter, nor traction busbars were available, it would be necessary to put in boosters, if with the triple-series method, for at least 30 volts apiece, making a total booster-rating capacity on a 1-hour discharge equal to 198 k.w. (30 volts × 6,650 amperes). Even this would be a distinct saving over the arrangement shown in Fig. 9, where the aggregate capacity is 236 k.w. (exclusive of spares), and a still greater gain over the arrangement shown in Fig. 6 where the capacity is

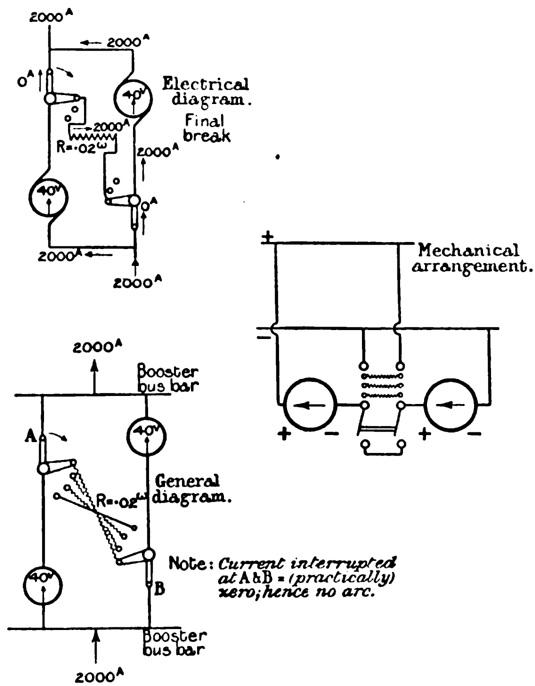


FIG. 16.—Parallel to Series.

730 k.w. In Fig. 15, however, it would be necessary to draw upon the fourth or reserve booster armature during charging (see Fig. 14), and it would be further necessary to arrange that the fields of all the boosters could for short periods be put under double the normal pressure, and also that, by speeding up the motor armature by some 30 per cent., the requisite volts on charging could be obtained.

It will be obvious that the arrangement in Fig. 15 would not be practicable if it were not feasible to make the change from series to parallel without interrupting the circuit. The author does not know of any arrangement actually on the market for performing this operation,

but he sees no reason why it should not be quite practicable to combine with the double-throw switches shown in Fig. 14 certain auxiliary contacts which will perform the requisite sequence of operations. Fig. 16, for instance, shows diagrammatically how the operation of going from parallel to series might be performed, and Fig. 17 shows how the reverse operation might also be performed.

Cells as a Pure Standby.

The employment of accumulators as a pure standby against failure of the generating plant has made considerable progress in the United

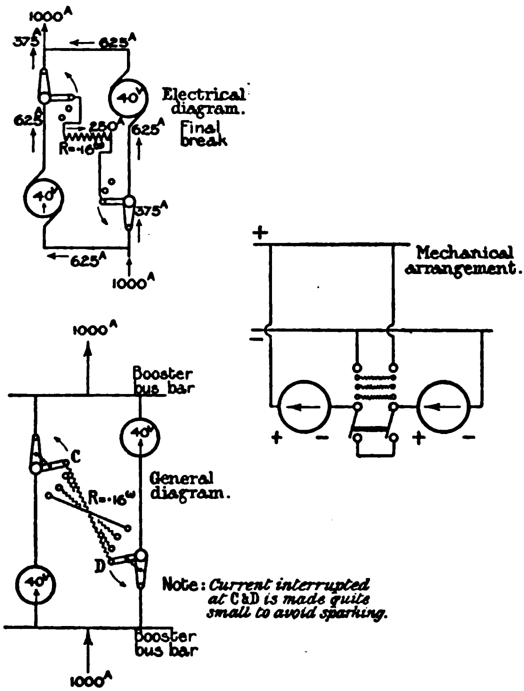


Fig. 17.—Series to Parallel.

States during the last year or two. The cells are worked without any boosters, there being a large number of regulating cells employed.

By the courtesy of the Chloride Company I am enabled to give the following particulars, which relate to the installation of 150 cells at the Sixteenth Street sub-station of the New York Edison Company. These cells are capable of giving 10,790 amperes for 1 hour, or 21,580 amperes for 21 minutes, or 32,370 amperes for 10 minutes, or 43,160 amperes for 6 minutes. It will be noted that the 6-minute rate is four times the 1-hour rate. The battery, as already stated, is

used as a pure standby, and simply floats on the busbars, and the regulating switches are automatically operated in such a manner that when a sudden discharge is required they will travel along rapidly to the contact required to give the prearranged busbar voltage at the prearranged discharge.

Of the total number of 150 cells the author understands that no less than 68 are regulating cells. The switches are designed to travel along from contact to contact under any current up to 40,000 amperes. The floor space required for a battery of 280 cells works out at about 0·3 sq. ft. per kilowatt for a busbar pressure of, say, 460 volts. It will be readily seen that such an arrangement compares very favourably as regards floor space with boilers, engines, and alternators; and as regards capital cost, the cost of cells alone is probably not much over £3 per kilowatt for a 6-minute rate, and compares very favourably indeed with any form of steam plant. Moreover, every central station engineer knows the extreme value of having standby plant which is absolutely ready to give instantaneously any discharge required from it. The battery is normally arranged to float on the busbars and receive a slight charge, so that at the commencement of any emergency demand the battery is giving its full voltage, and the number of cells to be installed is thus reduced somewhat below that given in Table A.

The extent to which this method of employing batteries has obtained favour in the United States will be understood when it is stated that in the year between June 1909 and June 1910 batteries have been installed in New York, Chicago, Brooklyn, Boston, and Washington, aggregating some 49,000 k.w. at the 6-minute rate. The author, however, thinks that, valuable as this special class of battery may be as a standby, the savings to be introduced by working the battery in a regular way as a substitute for the use of steam plant, where the load is of a peaky nature, are so great that it will not be found advisable to put in batteries exclusively for the one class of work. It may, perhaps, in certain cases, be advisable to put in a standby battery in parallel with a working battery, but the author hopes that, as far at least as the demands at the time of peak load are concerned, the reduction in booster capacity which he has indicated in this paper may enable boosters to be put in with such a margin that momentary overloads corresponding even to the 6-minute rate of the battery discharge may be taken by the boosters without fear of "flashing over" occurring when the armatures are in parallel circuit, as they would be on heavy discharges at the time of peak load. At other times of the day the momentary failure of the generating plant would probably do no more damage to the boosters (though then in series with one another) than if the breakdown occurred at the time of peak load, when they were in parallel with one another, the total load available being so much smaller.

Automatic and Non-Automatic Boosters.

The author suggests that where batteries are put in on a large scale for lighting purposes, it will generally be found preferable to put

in those batteries which deal with what may be called "time" peaks (as distinct from "instantaneous" peaks) arranged to be operated by hand-regulated boosters; but, since the voltage of a battery alters very considerably with its rate of discharge, it would also seem desirable to have a smaller battery, which might be of the nature of a buffer battery, to take up the "instantaneous" peaks by means of an automatic booster, and so keep the busbar pressure constant, while the main battery would be regulated by hand in such a manner as to enable boilers and engines to be shut down to the maximum possible extent. If a "buffer" battery were worked in parallel with a battery operated by non-automatic boosters, the former would, of course, immediately adjust itself to the rapidly varying demand, while the main battery would be unaffected thereby.

Economy of Accumulator Working.

The author hopes that a statement of the probable saving, in a concrete case, by the introduction of accumulators, in place of additional steam or gas generating plant, may not be without interest to members. The case chosen is one involving the delivery of an additional peak load of 1,450 k.w. on the direct-current busbars in a sub-station at a distance of 1 mile from the main generating station, such as might occur in a large town where the sub-station was in the most densely populated part and was used more for lighting than for power. The peak load represented in Figs. 18 and 19 is that observed at Dickinson Street, Manchester, for November 19, 1908, and already published in the technical press, and the author has shown in these two Figs. the effect of putting in a battery to deal, not with 1,450 k.w., but with 4,000 k.w. and 6,000 k.w., and the diagrams given are intended to show what a large proportion of the peak it would be possible to take up and still have a moderate margin of plant capacity available for charging purposes in the event of exceptional demands. (The author may here state incidentally that too much has, in his opinion, been made in the past of the impracticability of utilising accumulators on a large scale on account of fogs. He suggests that the savings would be very material if boiler and engine plant were put in capable, with the aid of the battery, of tiding over the worst fog, this steam plant, however, being normally shut down so as to avoid standing losses. The battery, if put in on a 2-hour rating, on the lines of Fig. 19, would, in the event of a fog coming on, give amply sufficient time for additional boilers to be started up, and at other times would produce large savings through enabling the largest generating sets in the station to be kept perpetually running at a high load factor.)

In what follows, a peak load of 1,450 k.w. delivered to the sub-station busbars will be considered, representing a load at the generating station of, say, 1,540 k.w., the transmission being by high-tension alternating current and rotary converters.

Table B.

Capital Costs for Extra Steam Plant to deliver 1,450 *k.w. on Direct-current Busbars of a Sub-station at* 1 *mile from Generating Station.*

	£
Cost of delivering 1,540 k.w. to E.H.T. busbars at main station (as per C. E. G. Shawfield's* estimate) at £13 per kilowatt	19,500
Cost of E.H.T. mains to sub-station at £1 2s. 6d. per kilowatt plus 5s. for spares = £1 7s. 6d. per mile per kilowatt	2,060
Cost of E.H.T. switchgear at sub-station, and of low-tension switchgear for rotaries and of direct-current cables in sub-station at £1 5s. per kilowatt	1,875
Cost of rotaries and transformers at sub-station at £2 10s. per kilowatt, plus 15s. for spares = £3 5s. per kilowatt	5,075
Cost of building and land for rotaries at 15s. per kilowatt	1,125
	29,635

Total capital cost, £20 per kilowatt (approximately).

Table C.

Steam Station.—Annual Cost of delivering an additional 1,450 *k.w. to Direct-current Bars for* 1 *hour daily* (540,000 *units*).

	Per Annum. £
Standing Charges at generating station (6½ per cent. taken for interest and sinking fund), as per Andrews and Porter,† exclusive of rates, taxes, or insurance, at £1·91 per kilowatt of maximum demand (1,540 k.w. at generating station)	2,940
Rates, taxes, and insurance, as per C. E. C. Shawfield,‡ at £0·25 per kilowatt of maximum demand (1,540 k.w. at generating station) ...	384
"Standby" coal, as per Andrews and Porter,* reduced to 1,540 k.w. (£0·79 per kilowatt) ...	1,220
Standing charges on E.H.T. mains, rotary, converters, sub-station cables, building, etc., at 6½ per cent. for interest and sinking fund on,	

* *Proceedings of the Incorporated Municipal Electrical Association*, 1907, p. 68.
† *Journal of the Institution of Electrical Engineers*, vol. 43, p. 3, 1909.
‡ *Proceedings of the Incorporated Municipal Electrical Association*, 1907, p. 68.

TABLE C (*continued*).

	Per Annum. £
say, £10,000 (see Table B) (£0·42 per kilowatt)...	650
Repairs on rotaries, mains, etc., at 3 per cent. on £10,000 (£0·195 per kilowatt)	300
Labour in sub-station, say (£0·097 per kilowatt) ...	150
Fixed charge (total)...	5,644
"Running" Charges :—	
Coal ("running" element), at 12s. per ton, as per Andrews and Porter's * estimate for main station, reduced to 4 per cent. load factor and to 1,540 k.w., and increased by 6 per cent. on account of losses in rotaries and in line ...	445
Oil, waste, and water, as per Andrews and Porter's * estimate, reduced to 4 per cent. load factor and to 1,540 k.w.	52
Running charge (total)...	497

Combined Charge :—

£3·89 per kilowatt of maximum demand (at sub-station) + 0·221d. per unit (coal at 12s.).

TABLE D.

Gas Station.—Annual Cost of delivering an additional 1,450 *k.w. to Sub-station Direct-current Busbars* 1 *mile distant,* 1 *hour daily* (540,000 *units*).

	Per Annum. £
Standing charges at generating station (6½ per cent. taken for interest and sinking fund) as estimated by Andrews and Porter,* exclusive of rates, taxes, and insurance at £2·28 per kilowatt of maximum demand (on 1,540 k.w.) ...	3,510
Rates, taxes, and insurance as per C. E. C. Shawfield's † estimate at £0·25 per kilowatt (on 1,540 k.w.)	384
"Standby" coal, as per Andrews and Porter,* at £0·35 per kilowatt of maximum demand of (on maximum demand 1,540 k.w.)	538
Standing charges on E.H.T. mains, rotary converters, etc., at 6½ per cent. for interest and sinking fund on £10,000 (see Table B) ...	650

* *Journal of the Institution of Electrical Engineers*, vol. 43, p. 3, 1909.
† *Proceedings of the Incorporated Municipal Association*, 1907, p. 68.

TABLE D (*continued*).

	Per Annum. £
Repairs on rotaries, mains, etc., at 3 per cent. on £10,000	300
Labour in sub-station, say	150
Standing charge (total)	5,532
Running Charges:—	
Coal, as per Andrews and Porter, reduced to 1,540 k.w., and to 4 per cent. load factor ...	124
Oil, waste, and water, as per Andrews and Porter, reduced to 1,540 k.w., and to 4 per cent. load factor	61
Running charge (total)	185

Combined Charge:—

£3·82 per kilowatt per annum + 0·0825d. per unit (coal at 12s.).

TABLE E.

Capital Costs for Accumulator Plant to deliver 1,450 *k.w. at* 460 *volts on Direct-current Busbars* (*for* 1 *hour daily*).

	£
Building at £1 10s. per kilowatt	2,175
242 cells (1 hour discharge)	8,500
3 boosters, each of 105 k.w., at £6 per kilowatt ...	1,890
Cables and switchgear...	1,500
	14,065

= £10 per kilowatt (approximately).

TABLE F.

Annual Cost of delivering 1,450 *k.w. on Busbars for* 1 *hour daily* (508,000 *units per Annum*) *by means of Accumulators.*

	Per Annum. £
Interest on cells at 3½ per cent.	298
Sinking fund (if cells bought out of revenue) at 5 per cent.	425
Maintenance on cells at 8 per cent. (for 20 years) ...	680
Interest and sinking fund on boosters, cables, building, at 6½ per cent. on £5,565	360
Maintenance of boosters, etc., at 3 per cent.... ...	167
Labour, say	250
Sundries	50
	2,230

TABLE F (*continued*).

Cost of coal, oil, water for 540,000 units at generating station + 50 per cent. waste = 810,000 units at 0·147d. (coal 8s. ton)	Standing charge per kilowatt of maximum demand = £1·54

Total cost = £1·54 per kilowatt + 0·22d.* per unit delivered per annum (coal at 8s.).

TABLE G.

Capital Costs for Accumulator Plant to deliver 1,450 *k.w. at* 460 *volts on Direct-current Busbars for* 2 *hours daily, by means of Accumulators.*

	£
Building at £2 per kilowatt	2,900
242 cells (2 hours' discharge)...	13,500
3 boosters each of 105 k.w., at £6 per kilowatt ...	1,890
Cables and switchgear...	1,500
	19,790

= £13·6 per kilowatt per annum.

TABLE H.

Annual Cost of delivering 1,450 *k.w. on Busbars for* 2 *hours daily* (1,016,000 *units per Annum*) *by means of Accumulators.*

	Per Annum. £
Interest on cells at 3½ per cent. on £13,520 ...	472
Sinking fund (if cells bought out of revenue) at 5 per cent.	675
Maintenance on cells at 8 per cent. (for 20 years)	1,080
Interest and sinking fund on boosters, building, and cables, etc., at 6½ per cent. on £6,290 ...	409
Maintenance of boosters, building, cables, etc., at 3 per cent. on £6,290	188
Labour, say	300
Sundries	75
	3,199

= £2·21 per kilowatt per annum standing charges.

Cost of coal, oil, water for 1,080,000 units at generating station + 50 per cent. waste = 1,620,000 units at 0·147d. (coal at 8s.) per unit generated.

Total cost = £2·21 per kilowatt + 0·22d. per unit delivered per annum (coal at 8s.).

* 0·147d. per unit generated.

Table J.

Capital Cost for Accumulator Plant to deliver 1,450 k.w. at 460 volts on Direct-current Busbars for 5 hours daily.

	£
Building at £3 per kilowatt	4,350
242 cells (5-hour discharge)	27,000
3 boosters, each of 105 k.w.	1,890
Cables and switchgear...	1,500
	34,740

= £23·9 per kilowatt per annum.

Table K.

Annual Cost of delivering 1,450 k.w. on Busbars for 5 hours daily (2,540,000 units per Annum) by means of Accumulators.

	Per Annum. £
Interest on cells at 3½ per cent. on £27,000 ...	945
Sinking fund (if bought out of revenue) at 5 per cent....	1,350
Maintenance on cells at 8 per cent. for 20 years ...	2,160
Interest and sinking fund on boosters, cables, buildings, etc., at 6½ per cent. of £7,740 ...	503
Maintenance of boosters, etc., at 3 per cent. ...	232
Labour	350
Sundries	100
	5,640

= £3·89 per kilowatt standing charge.

Cost of coal, oil, water, 2,700,000 units at generating station + 50 per cent. waste = 4,050,000 units at 0·147d. = £2,610.

Total cost = £3·89 per kilowatt + 0·22d. per unit, delivered, per annum (coal at 8s.).

In Table B is given an estimate of the capital cost involved in providing for an additional 1,450 k.w. of peak load on the direct-current busbars of a sub-station at 1 mile from the generating station. In Table C is given the approximate annual cost of delivering 1,450 k.w. for one hour daily to the sub-station busbars. The same table may be taken as giving the approximate cost for two hours or for five hours, the running charges being merely altered in proportion to the increased load factor. In Table D is given the approximate annual cost of delivering 1,450 k.w. to sub-station busbars for one hour daily, using gas plant at the main station. In Table E is given the approximate capital cost for accumulator plant (at the sub-station) to deliver

1,450 k.w. to the sub-station busbars for one hour daily. In Table F is given the approximate annual cost for delivering 1,450 k.w. for one hour daily by means of accumulators. In Table G is given the approximate capital cost for delivering 1,450 k.w. for two hours daily on sub-station busbars by means of accumulators. In Table H is

Table L.

Annual Charges for 1,450 k.w. (additional) Maximum Demand on Sub-station Busbars.

(Remainder of Day supplied from Rotaries.)

Peak Hours per Day.	Equivalent Load Factor (approximate).	Steam Plant (Coal at 12s.).			Battery (Coal at 12s.).		
		Fixed Charges per Kilowatt.	Running Charges per Unit.	Total Annual Sum.	Fixed Charges per Kilowatt.	Running Charges per Unit.	Total Annual Sum.
	Per Cent.	£	d.	£	£	d.	£
1	4	3·89	0·221	6,141	1·54	0·330	2,976
2	8	3·89	0·221	6,638	2·21	0·330	4,691
5	20	3·89	0·221	8,129	3·89	0·330	9,360
		Gas Plant (Coal at 12s.).			Battery (Coal at 12s.).		
1	4	3·82	0·082	5,717	1·54	0·120	2,507
2	8	3·82	0·082	5,902	2·21	0·120	3,753
5	20	3·82	0·082	6,457	3·89	0·120	7,025
		Steam Plant (Coal at 8s.).			Battery (Coal at 8s.).		
1	4	3·89	0·150	5,992	1·54	0·220	2,752
2	8	3·89	0·150	6,340	2·21	0·220	4,243
5	20	3·89	0·150	7,384	3·89	0·220	8,250

given the approximate annual cost for delivering 1,450 k.w. for two hours daily by means of accumulators. In Table J is given the approximate capital cost for delivering 1,450 k.w. for five hours daily by means of accumulators. In Table K is given the approximate annual cost of delivering 1,450 k.w. for five hours daily by means of accumulators. In Table L a summary is given of the above tables.

It will be seen that on a 1-hour basis and with coal at 8s. per ton the total annual cost with the batteries is only £2,752 as against £5,576 when delivering the power direct to the busbars without cells by means of rotary converters. It will be noted that the cost of the energy wasted in the cells and boosters is in the case of the gas plant only 0·04d. per unit, and in the case of the steam plant with coal at 8s. per ton it is only 0·07d. per unit delivered to busbars. With coal at 12s. per ton, and with steam plant, the cost of the energy wasted in the cells and boosters is 0·11d. per unit. The higher the fixed charges and the lower the running cost of the generating plant, the better does the battery show up as a substitute for it. It would seem, therefore, that where the average duration of the load supplied by the accumulators is from one to two hours, as in Figs. 18 and 19, and coal is moderately

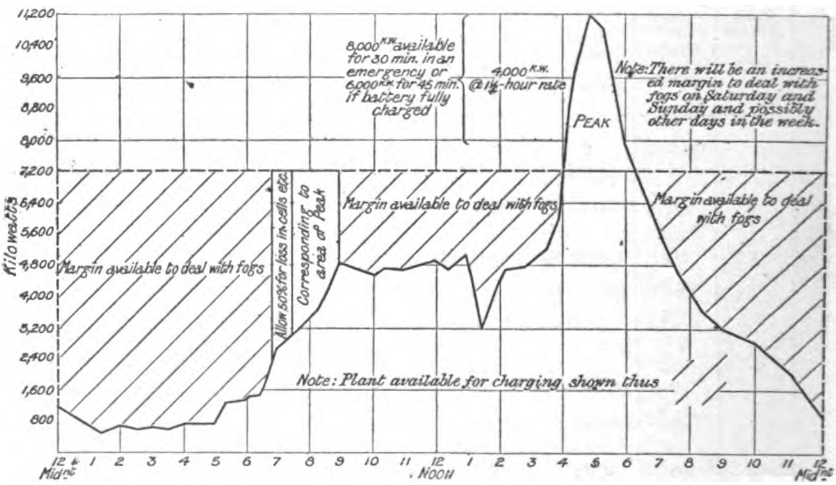


FIG. 18.—1½-hour Peak.

cheap, there is undoubtedly a good case for accumulators. Even, however, where coal is dear there is generally a sufficient saving in standby losses, on boilers and engines, which can be entirely shut down to make the value of the coal so saved fully equal to that lost in the inefficiency of the battery. This is exemplified in the case of Manchester where the coal consumed per unit delivered to busbars, at Dickinson Street, for a particular period of the year, is stated to have been reduced by 25 per cent., this taking account of the losses in the accumulators and boosters.

ACCUMULATORS WITH ALTERNATING CURRENT.

The introduction of the split-pole rotary converter, as developed in the United States, has given an incentive to the use of batteries on alternating-current systems as equalisers of the load. No doubt the

employment of accumulators on alternating-current systems would be greatly extended if some less expensive and more flexible means could be introduced for charging and discharging them than that employing rotary converters, though this is perfectly practicable. For instance, if an ideal rectifier were available, a considerable stimulus would be given to the introduction of batteries on the premises of large consumers who were agreeable to take a restricted hour supply at cheap rates. The "Nodon" valve and the mercury vapour rectifier, and some other forms of rectifier, are on the market, but appear to be very limited in their capacity. They might, however, be useful for the charging of electrically driven vehicles.

The author may perhaps be permitted to mention that he has himself devised a rectifier which he anticipates will permit of momentary

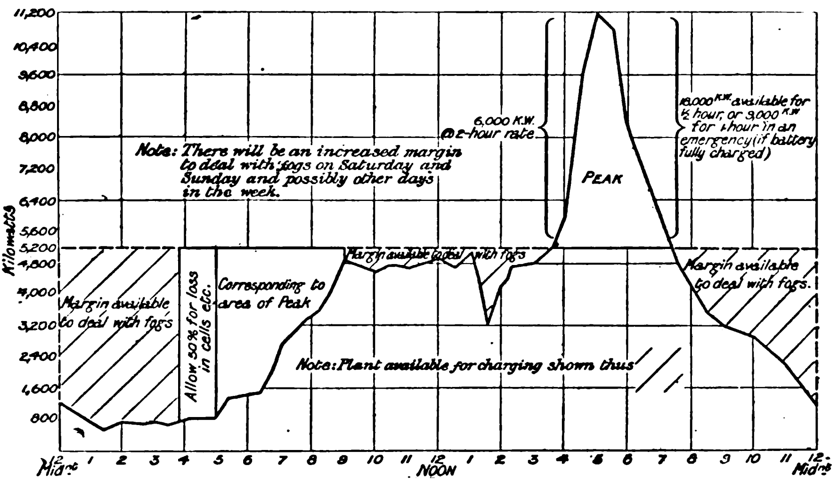


FIG. 19.—2-hour Peak.

overloads being passed through it many times larger (proportionately) than those which would cause the commutator of a rotary converter to flash over, and which should also be capable of dealing with large currents and of commutating direct currents into alternating currents. The question of the employment of batteries on alternating-current systems is increasing in importance, because not only can the load factor be improved thereby, but also the power factor.

Improving Power Factor of Alternating-current Systems by Means of Accumulators.

The increasing use of induction motors on systems distributing with alternating-current supply, and the fact that, when lightly loaded, such motors have a very poor power factor, is causing many central station engineers anxious thought, the lagging wattless currents

on such systems interfering seriously with good regulation and with generator capacity.

Where the system is only in part alternating current, and a considerable part of the energy is sold as direct current, provided by means of rotary converter sub-stations, it will probably appear to most engineers that in such case there may certainly be, under suitable conditions, scope for a battery; but it will probably be almost accepted as a foregone conclusion that where the distribution is principally by alternating-current mains there is no scope whatever for a battery, unless in long-distance schemes, like those of some of the power companies, where sub-stations already exist containing rotating machinery, whether for tramways or for lighting.

The author thinks, however, that if it can be shown that, even in pure alternating-current distribution, the employment of battery sub-stations will not only reduce the amount of generating plant (including boilers, etc.) in the main station, as well as the aggregate section of the E.H.T. feeders emerging therefrom, by some 20 to 30 per cent., but will also reduce the amount of wattless current sent out from the main station to an insignificant amount, and thereby liberate probably another 10 to 20 per cent., or even more, of the whole of the electrical part of the plant (including feeders), engineers will think twice before they dismiss the double advantage on the sole objection that to introduce sub-stations with rotating machinery requiring skilled attention, in place of feeders, would be a retrograde step. As regards reliability of supply, it certainly would not be this, even if no pecuniary saving were obtained.

The cost of extensions to the sub-station building, the rotaries, the batteries, and the cost of attention, in contradistinction to the cost of extra steam plant at the generating station, has already been worked out in this paper, and is given in Tables B, E, G, J.

The cost of entirely new sub-stations, rotaries, etc., will not be materially different from the figures already given (except that rotaries and switchgear have to be added); and, if a good case has been made out for putting in accumulator plant in existing rotary converter sub-stations to save the first 20 to 30 per cent. of the generating-station plant and feeders above alluded to, it should be pretty clear that the additional conversion losses in retransforming back to alternating current are more than compensated by the additional 10 to 20 per cent. of generating plant and feeders saved on account of improved power factor.

As a matter of fact, the losses in the double conversion would hardly be any more than in the single conversion, because the principal loss is in the battery itself, and that remains practically unaltered; and, further, because the losses in boosters under present arrangements are very heavy and probably nearly equal the losses that would be incurred by having split-pole rotaries both to charge and discharge the batteries, thus doing away with boosters altogether.

In any case, the tables given will permit of the extra cost of the

wasted energy being readily compared with the savings introduced by the reduction in steam plant and feeders at the main station.

The author may perhaps be allowed to state here his proposals for improving the power factor in a pure (or mixed) alternating-current system. Referring to Fig. 20, the rotary converter or motor-generator (A) and its battery (C) are used for taking up the peaks of the load in a manner well understood. The second rotary converter, motor-converter, or motor-generator (B) is a synchronous machine and is over-excited in such a manner that it runs as motor, fed from the alternating-current line, and draws a leading wattless current therefrom sufficient in value to compensate for the lagging wattless currents taken by the consumers' motors.

The special feature of the author's proposal is that the rotary converter (B) is enabled to find a useful load for itself by charging the

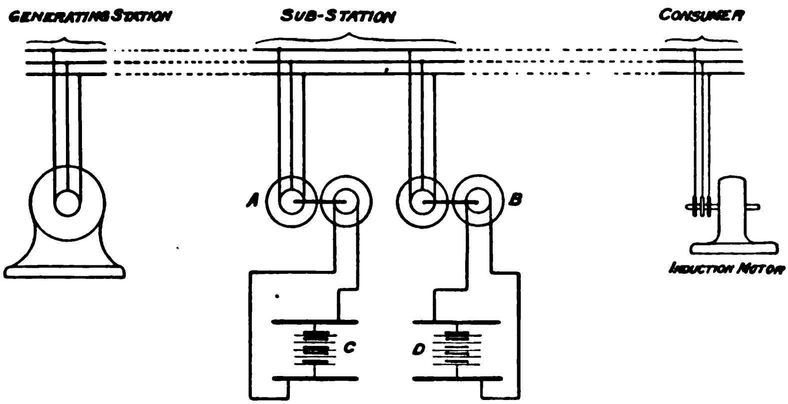


FIG. 20.

battery (D), and thus a given kilovolt-ampere motor load can be dealt with with a much smaller expenditure in synchronous machines than would otherwise be the case.

When the evening peak load comes on, the charge in the battery (D) is available in assisting the rotary (A) to deal with the load; and the motor-generator (B) may either be used to perform phase-changing by itself or, if not needed for that, is available to assist the motor-generator (A) in dealing with the peak.

Fig. 21 shows the phase conditions obtaining when the motor (B) is doing phase-changing and is merely "floating" on the battery or disconnected entirely from it, and Fig. 22 shows the corresponding phase conditions when it is charging the battery at the rate of 3,750 k.w.

In Fig. 21 a synchronous motor of 1,210-k.v.a. rating will just compensate for 2,000 k.v.a. of induction motor load; in Fig. 22 approxi-

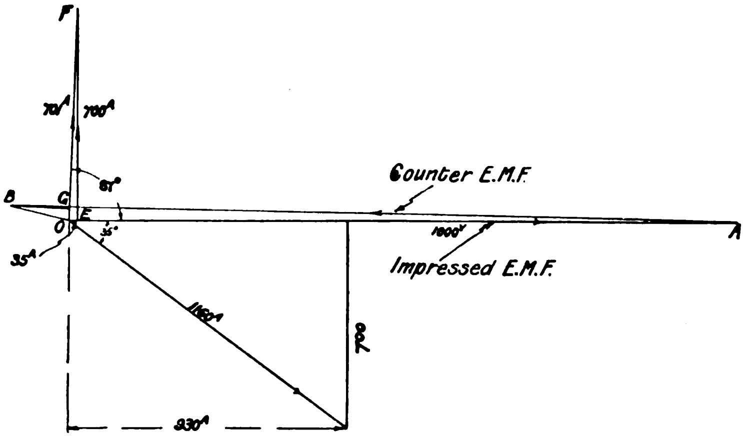


FIG. 21.

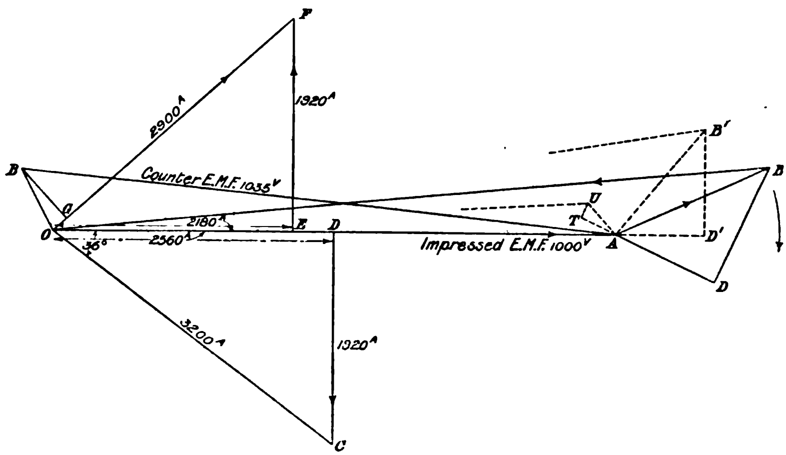


FIG. 22.

O F = Resultant current in rotary.
E F = Leading wattless current in rotary.
O C = Resultant current in line before rotary introduced.
D C = Lagging wattless current of consumers' motors.
A B = Impedance volts in line to sub-station.
A U = " " " consumer.
O B = Volts at generating station.
O A = " sub-station.
O U = " consumer.
O B = Phase of volts at generating station before rotary introduced.
O B' = " " " " after " "

mately the same amount of kilovolt-ampere (*i.e.*, 1,250 out of the 5,000 k.v.a.) rating will compensate for 5,500 k.v.a. of induction motor load, a gain of 3,500 k.v.a. of consumers' load. Without the battery a synchronous motor for some 3,000 k.v.a. would have had to be installed, with correspondingly increased machine losses perpetually being incurred.

An Alternative to Batteries as a Means of a Peak Load Supply.

Since the rest of this paper was written an abstract has appeared in the *Electrical World* of New York of a paper read before the American Street and Urban Engineering Association by Mr. H. G. Stott, in which the use of batteries for peak loads is unfavourably compared with a scheme put forward by him for providing the extra power for extensions (in stations employing reciprocating engines) by adding exhaust turbines to carry this load, by adding grate surface to the existing boilers, and by forcing the boilers during the time of peak load.

Mr. Stott gives curves of cost per kilowatt-hour plotted (apparently) with load factor, and in Fig. 23 the author reproduces this curve (A B), while for comparison the estimated costs given in Tables C and F of the present paper are plotted on the same sheet. It will be noticed that the author's curve (C D), representing interest and sinking fund, repairs and labour, closely agrees with Mr. Stott's curve (A, B), as to which latter the author is fairly clear that this curve does not include more than interest and depreciation. To assume the contrary will, however, be safe.

The disadvantage under which Mr. Stott's proposal labours is that the standby coal required to keep the boilers going right through the night will still be required much as before. Moreover, the steam units cannot be so economically loaded up at all times of the day and night as by the use of batteries.

Curve G H takes account of the standby coal, obtained in the manner indicated in Messrs. Andrews and Porter's paper,* and while it may be agreed that the amount of the standby coal is still a debatable point, there can be no doubt that if a battery-charging load could be provided after midnight, coupled with a reduction in the number of boilers and engines required during the day, a considerable saving in coal would be effected. The curve G H includes also a sum for rates, taxes, and insurance. (To make the statement complete a sum for management should be added.)

Another point that Mr. Stott has apparently overlooked is that his scheme introduces the extra capacity at the wrong point; it should be preferably introduced at the sub-station. The extra cost of delivering the energy at the sub-station direct-current busbars is shown by the curve J, K.

* *Journal of the Institution of Electrical Engineers*, vol. 43, p. 3, 1909.

While, therefore, to provide additional kilowatt capacity at the time of peak load will require, on Mr. Stott's scheme, additional outlay on exhaust turbines (in some cases cancelling the overload capacity

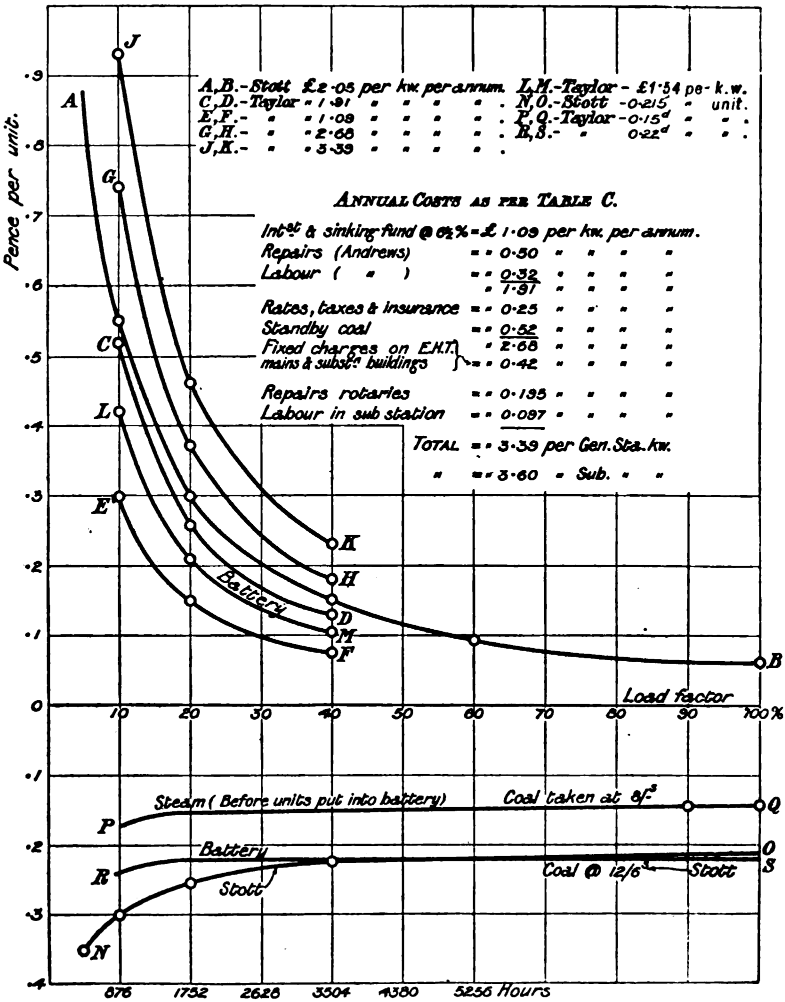


FIG. 23.

of the existing engines), and on accessories to boilers, he will have to debit it further with additional alternators, feeders, and sub-station plant. The only saving is therefore on boilers and steam piping, whereas all the other charges (which are practically proportional to

the kilowatt capacity of the generating station) keep constant. The effect of his proposals might possibly be to lower the curve J K to a position somewhat above that now occupied by the curve G H; whereas with the battery (1-hour) scheme the curve L M represents the total cost of the extra units, so far as fixed charges are concerned.

With a 2-hour peak, the battery cost curve is brought to a position slightly above the curve (A B); but there are many stations where the *mean* value of the duration of peak load is much less than 2 hours, provided that not more than 30 per cent. of the peak is taken up by the cells. It is also worth bearing in mind that, with the overload capacities now possessed by alternating-current generating plant, a period of half an hour on either side of the peak (provided that a period for cooling is allowed while the batteries are relieving the main plant), can be taken quite well in cases where the continuation or the overload right through the peak would be too severe on the generating plant.

Thus, a 1½-hour battery might be caused to "carry over" a 2-hour peak, aided by the overload capacity of the plant; or a 2-hour battery might be caused to deal with a 3-hour peak, the latter the more easily as there would be a longer period for cooling down. It must also be remembered that the battery is capable of much greater emergency demands than the generating plant, or boilers.

The author has dealt somewhat in detail with this matter, as Mr. Stott's proposals, coming from an engineer of his experience, require to be carefully considered; but he believes that for peaks of short duration, say up to 2 hours, the batteries will be found decidedly the cheaper, and moreover, a smaller additional staff will be required than with the turbo-scheme. The question of power factor also has to be considered, and is a further inducement towards the use of batteries.

Conclusions.

The fact that batteries can now be constructed, and are in use, which will give outputs up to 40,000 amperes, shows that the lead-plate type of accumulator has now passed the experimental stage from the point of view of reliability, and central station engineers need no longer be afraid that if they put in a battery they may have to scrap it at the end of two or three years. Battery makers of repute are now to be found who will undertake the maintenance of cells for periods of ten to twenty years. Even if this were not so, the new Edison cell appears to have wonderful characteristics, as may be seen from tests recently published in the *Electrician*, and may be described as practically "fool-proof." The author is, unfortunately, unable to give an idea of its cost; but as things stand, it would seem to be quite safe to install large batteries of the lead-plate type, and even if, in a few years' time, the long-expected ideal battery should make its appearance, no particular loss would be involved, provided a life of some seven years had already been obtained out of the lead-plate battery.

APPENDIX I.

List of Tudor Batteries having an Output of over 500 K.W. supplied by the German Tudor Company.

Town.	Maximum Output.			Number of Batteries.
	Amperes.	Volts.	Kilowatts (on a 3-hour Rating).*	
Germany.				
Altona.				
Funkstrasse	2,016	220	442	2
Friedenstrasse	1,224	220	269	1
Berlin Electricity Works.				
Mauerstrasse	10,368	220	2,280	4
Judenstrasse	10,368	220	2,280	4
Schiffbauerdam	5,184	220	1,140	2
Alte Jacobstrasse	7,776	220	1,710	3
Koppenplatz	5,184	220	1,140	2
Taubenstrasse	7,776	220	1,710	3
Voltastrasse	3,024	440	1,330	2
Konigin-Augustastrasse ...	4,392	440	1,931	3
Wilhelmshavenerstrasse ...	3,024	440	1,330	2
Mariannenstrasse	4,536	440	1,995	3
Palisadenstrasse	3,024	440	1,330	2
Zossenerstrasse	3,024	440	1,330	2
Rudolfplatz	1,944	440	755	1
Frenzlauer Allee	1,944	440	755	1
Berlin-Schoneberg (South-west Electricity Works).				
Motzstrasse	4,968	440	2,184	2
Tempelhoferweg	1,003	440	441	1
Halensee	1,296	440	570	1
Krankenhaus	288	440	127	1
Breslau.				
Kl. Groschengasse	1,512	440	565	1
Schiesswerder	702	440	309	1
Gaöitzstrasse	432	440	190	1
Michaelisstrasse	432	440	190	1
Bremen.				
Gr. Hundestrasse	5,652	220	1,242	3
Meinkenstrasse	1,422	220	312	2
Freihafen	304	220	67	1
Wachmannstrasse	504	220	111	1
Schlachthofstrasse	324	220	71	1

* Double these values for a 1-hour rating.

APPENDIX I. (*continued*).

Town.	Maximum Output. Amperes.	Volts.	Kilowatts (on a 3-hour Rating).*	Number of Batteries.
GERMANY (*continued*).				
Dusseldorf.				
Bleichstrasse	3,520	220	773	3
Badeanstalt	1,504	220	330	3
Carlschule	1,008	220	221	1
Rheinhafen	504	220	110	1
Rethelstrasse	600	220	132	1
Elberfeld.				
Hofkamp	2,400	220	528	1
Hagen i.w.	1,512	440	665	1
Halle a.S.	2,412	440	1,060	2
Hamburg.				
Barmbeck	4,320	220	950	2
An der Bille	4,536	220	996	2
Caralinenstrasse	2,592	220	570	2
Eilbeck	1,512	220	332	1
Eppendorf	1,512	220	332	1
Gr. Neumarkt	6,048	220	1,328	2
Gr. Reichenstrasse	5,076	220	1,116	1
Harvesthude	6,480	220	1,424	2
Pferdemarkt	6,048	220	1,328	2
Poststrasse	2,098	220	461	2
Sophienstrasse	1,584	220	348	2
St. Georg	4,464	220	982	2
Uhlenhorst	1,768	220	388	2
Hanover	1,440	440	633	1
	1,440	220	316	1
Kiel	2,160	440	950	2
Konigsberg l. Pr.	1,188	440	523	2
Leipzig.				
Magazingasse...	1,156	440	508	2
Lossnig	360	220	79	1
Reudnitz	1,800	440	792	1
Plagwitz	1,224	440	538	1
Schenkendorfstrasse ...	360	440	158	1
Neudorfchen	360	440	158	1
Gohlis	360	440	158	1
Connewitz	360	440	158	1

* Double these values for a 1-hour rating.

APPENDIX I. (*continued*).

Town.	Maximum Output. Amperes.	Volts.	Kilowatts (on a 3-hour Rating).*	Number of Batteries.
GERMANY (*continued*).				
Lubeck	1,332	440	586	2
Munich.				
Arcisstrasse	3,024	220	664	2
Carlstrasse	3,672	220	807	2
Krankenhaus III	720	220	158	1
Muffatwerk	5,516	220	1,234	3
Neuhausen	792	220	174	1
Oberpollinger	1,224	220	269	1
Prinzregententheater ...	1,188	220	261	1
Rathaus	4,896	220	1,076	3
Schillerstrasse	3,024	220	664	2
Ausstellungspark	1,512	220	332	1
Wurzerstrasse	3,096	220	680	3
Stuttgart.				
Marienstrasse	5,892	220	1,296	3
Stockach	792	220	174	1
Marbach	96	110	10	1
Interimtheater	216	220	47	1
Gewerbehalle	351	220	77	1
Markthalle	1,584	220	348	1
Unterturkheim	1,080	220	237	1
Cannstatt	432	110	47	1
Poppenweiler	252	110	28	1
Munster	360	220	79	1
Lowentor	118	220	26	1
HOLLAND.				
Rotterdam.				
Sub-station A...	756	440	333	1
" B...	1,008	440	444	2
" C...	756	440	333	1
DENMARK.				
Copenhagen.				
Veyterbro	2,160	440	950	1
Osterbro	2,160	440	950	1
Gothersgade	1,908	440	840	1

* Double these values for a 1-hour rating.

APPENDIX I. (*continued*).

Town.	Maximum Output.			Number of Batteries.
	Amperes.	Volts.	Kilowatts (on a 3-hour Rating).*	
SWEDEN.				
Stockholm.				
Brunkedergstation	3,456	220	760	1
Djurgardstation	288	440	127	1
Katarinastation	1,044	440	459	1
Kronebergstation	513	440	225	1
Thulestation	2,088	440	919	1
Vartawerk	504	440	222	1
Goteborg	3,996	240	959	1
NORWAY.				
Christiana.				
Central Station	1,728	440	760	1
Mollergade	720	440	316	1
ARGENTINA.				
Buenos Aires.				
Pezes	1,656	440	728	1
Pesades	3,996	440	1,758	1
Central Station	1,152	440	506	1
Bustamente	2,016	440	888	2
La Capital	792	220	174	1
Salta	504	440	222	1
CHILI.				
Santiago	4,104	440	1,806	3
Valparaiso	2,016	440	887	2

* Double these values for a 1-hour rating.

APPENDIX II.

BATTERIES INSTALLED IN SOME LARGE U.S.A. CENTRAL STATIONS.

Locality.	Number of Batteries.	Aggregate Capacity at 1-hour Rate.
		Kilowatts.
New York (for Edison Company) ...	44	34,342
Chicago (for Commonwealth Company)	26	24,216
Brooklyn (N.Y.)	11	7,174
Boston (for Edison Company)	9	7,016
Philadelphia	4	2,277
Total	94	75,025

APPENDIX III.

With regard to the author's comments on pages 421, 422, and 423, it seems desirable to add a few more remarks.

The present paper contemplates more particularly the use of accumulators as a substitute, up to a fixed limit, for additional steam plant, for the purpose of dealing with the regular peak load of the station. It is also intended to use the same battery for supplying a momentary load in the event of a breakdown of any section of the plant. Its utility under these circumstances cannot be questioned, and the fact that it is ready instantaneously for use gives it an immense advantage over any proposals employing steam plant for such a purpose.

The author wishes, however, to point out the great value that a battery of the New York "Exide" type would have when used as a supplement to the steady-discharge battery, the latter being employed for dealing with the regular peak and the former purely for exceptional demands which only occur very rarely, such as breakdowns or fogs.

It is found that if a battery be constructed to stand a comparatively few discharges during its lifetime—say, perhaps, 10 per cent. of what would otherwise be expected—such a battery can be made for perhaps half the cost, and will take up perhaps only two-thirds the space of the ordinary battery.

To form some idea as to the relative cost of overloaded boilers and steam plant, as proposed by Mr. Stott, as compared with this type of battery (used as a supplement only), the author has made the very liberal assumption that, by putting in non-condensing steam turbines

and boilers designed purely for emergency work, an overload capacity 100 per cent. above the "continuous" rating could be obtained for one hour; and he finds that the savings on turbines, boilers, condensers, cooling towers, etc., would result in a possible reduction of £7 10s. per kilowatt in the capital cost, which reduces the capital cost figure given in Table B from £19 10s. to £12 (approx.). This means an annual saving of £0·44 per kilowatt on interest and depreciation, and with other savings on labour, etc., this would amount to a total of £0·84 per kilowatt per annum saved, or a net result of approximately £3 per kilowatt per annum.

The total costs of the "Exide" battery for 1-hour discharge, corresponding to the above, only amount to £0·89 per kilowatt per annum.

On a 20 per cent. load factor the relative fixed charges are respectively 0·411d. per unit and 0·122d. per unit. On a 10 per cent. load factor these figures are, of course, doubled. There seems no question which is the better method.

Even if the battery were put in for a 2-hour discharge, the cost only works out to £1·385 per kilowatt per annum, or to 0·19d. per unit for a 20 per cent. load factor, as against 0·41d. with steam plant (overloaded 100 per cent. for 2 hours).

The cost of the battery has been assumed to be only one-half of present prices for ordinary type of cells.

APPENDIX IV.

The following is an application of the figures given in Tables B, C, E, F, to Fig. 19 of the paper, showing the load at Dickinson Street. The area of the curve represents 93,800 units per day, or 33,800,000 units per annum—that is, a 35 per cent. load factor. We may compare the cost of putting in steam plant for the whole 11,200 k.w. as against the cost of installing steam plant for 5,200 k.w. and battering plant for 6,000 k.w., at a 1½-hour rate; which would supply a 2-hour peak. The fixed charges for the 11,200-k.w. plant at £3·89 per kilowatt per annum are equal to £43,500; and the "true" running costs at, say, 0·15d. per unit equal £21,100, giving a total of £64,600 for the all-steam scheme. Considering next the battery scheme, we have as follows: 5,200 k.w. of steam plant at £3·89 per kilowatt = £20,200 per annum; 6,000 k.w. of battery plant at £1·58 per kilowatt, or £9,480 per annum, giving a total for fixed charges of £29,680 per annum. To this has to be added £21,100 for running charges, as for steam and £1,200 for lost units in the battery and boosters, giving a total for the battery scheme of £51,980. But, as no margin is provided in the battery plant beyond that of the normal peak, it is desirable to provide a second battery (which could be of the Exide type), for use solely for emergency conditions, having a 6,000-k.w. capacity for 1½ hours. This ("Exide") battery would add to the fixed charges a sum of probably some £6,300 per annum (6,000 k.w. at £1·05), making a total of £58,280, thus giving a saving of £6,320 per annum over that of the all-steam plant. It may be

mentioned that the sum of £43,500, given in the steam scheme for fixed charges, included £3,100 on the 6,000-k.w. plant, representing standby coal, which is entirely saved on the battery scheme.

Discussion.

Mr. Jenkin.

Mr. B. M. JENKIN: The author has put before us some very interesting points in connection with batteries. One of the most interesting is his suggestion to split the booster up into three parts instead of making it with only one generating armature. This makes it possible to reduce the size of the booster very much. This is clearly shown by the author in Figs. 6 to 11, in which he compares the usual method, where the booster is made with one generating armature which deals with the whole current, with his own method, in which the triple booster has three armatures which are worked in series or in parallel as required. For comparison it should be noted that in the latter case there are 280 cells in the battery as compared to 240 cells in the former case. This, as he points out, is one of the reasons why the booster is reduced in its kilowatt output. I would suggest that his method of working should be carried still further. The chief value of a battery is on the discharge, when it should give the maximum possible output. Therefore, I would suggest that it is a mistake to make the battery do anything more at that time than deliver current to the busbars, all of which can be used for the load. As long as a booster is used to help to discharge the battery, some of that most valuable current on the emergency is being used to drive the booster. If the number of cells be increased until the emergency discharge can be got without the use of a booster, the whole of the current that comes out of the battery is available for the feeders. Power to charge the battery can be afforded very much more easily than to discharge it, because during charge ample plant is available, and a great deal more power can be put into the booster economically and advantageously during that period than during the discharge. That occurs to me as the result of what the author has pointed out. The next point is the question of how these boosters should be switched. The author leaves this rather vague, and suggests the switch shown in Figs. 16 and 17 for changing the boosters from working in series to working in parallel. I have been unable to follow the reason for that complicated proposal, and do not think it is really necessary. He has suggested in Fig. 14 that these separate commutators of the booster generator, or at least two of them, might be connected to the same armature in a single field. That, I think, is unsatisfactory because the boosters cannot then be handled independently of each other. Each generating armature should be in its own field so that its voltage can be regulated independently. If this is done, to change the three armatures in series to three in parallel, one simply reduces the volts on one of the armatures until it reaches zero, closes a short-circuiting switch, and cuts out that booster armature. The same thing is done with the next, which leaves one

armature in series with the battery. This condition must be reached before it is possible to put them in parallel. Up to this point the discharge of the battery is limited to the current capacity of one booster armature. With the author's arrangement there must be this transition stage. An examination of Fig. 15 makes this clear. As the current increases, a second armature is put in parallel. To do this it is run up to the same volts as the booster already in circuit, and is then switched in in parallel. It is not necessary to have any complicated switch with resistance to do this, but the armatures must be in separate fields, so that each one can have its voltage regulated independently of the other. Mr. Jenkin.

I would suggest that the absence of the booster during discharge is a thing that should be aimed at, especially if the battery is to be regarded as a standby in emergency, when the discharge current may rise to its full value at once, giving no time to switch over the boosters. I do not think any switchboard hand would care to do such a tricky thing as taking three armatures in series and changing them to three

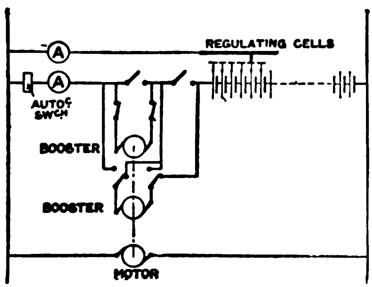


FIG. A.

in parallel on an emergency when he wants to use his battery as a standby; I think he would certainly find that extremely difficult. Even in the case of Fig. 15 of a normal 1-hour discharge the author shows that he works all boosters in series during the first quarter of an hour of discharge, during the next half-hour he runs them in parallel, and then for the last quarter of an hour he puts them in series again. That involves a great deal of switching when the maintenance of the load depends entirely on the continuity of the battery discharge. The author further suggests in that arrangement that there should be regulating cells. But previously he has told us that regulating cells are disadvantageous, as it is extremely difficult to charge the cells connected to the regulating contacts. In spite of that, he shows in his arrangement in Figs. 9, 10, and 11, regulating cells in series with his booster connection. I would suggest that the better plan is to use regulating cells and at the same time put in a battery with a sufficient number of cells to take the emergency discharge. Then one is entirely independent of the boosters in emergency. But in order

Mr. Jenkin. to work those regulating cells to the same extent as the main battery, I think the booster should be put in parallel with the regulating cells as shown below in Fig. A. The booster is placed in parallel with the regulating switch circuit. During charge, the whole of the cells are equally charged through the booster. The regulating switch is adjusted to suit the busbar volts, and the booster voltage is adjusted to give the required charge and at the same time keep the current through the regulating switch circuit at zero. During normal discharge the same method is followed, so that all the cells are equally discharged. During the beginning of the discharge the booster is run inverted and the motor delivers current to the busbars. At the end of the discharge the switch is on the end cell and the booster shut down. In emergency the heavy discharge is taken through the regulating switch circuit, and the booster is automatically cut out as the switch is moved to the end cell. The regulating switch circuit is available for emergency discharges at all times, and is not affected by the booster connections which might be set with armatures in series or in parallel, charging or discharging. I think, therefore, that might be a better way of dealing with the problem than any the author has described. I do not think it is mentioned in the paper, and I do not know that it is used. I have not tried it myself, but I hope to do so on the next occasion when I have to put in a big battery.

Mr. Shawfield. Mr. C. E. C. SHAWFIELD: The title of the author's paper is: "Battery Economics and Battery Discharge Arrangements," but I am afraid that part of his paper which relates to the economical use of batteries, particularly as affecting the coal bill, is very much overshadowed by that part which deals with the discharge arrangements. I had rather hoped, when he told me he was writing the paper, that he would have gone very fully into the possible savings which can be effected in the boiler house by the judicious use of batteries for peak loads. There is another section of his paper, too, with which I can hardly agree, and that is his advocacy of the use of batteries for standby purposes, particularly where he suggests putting in discharge arrangements, boosters, etc., capable of enabling a battery to be discharged at a 5-minute rate. I can hardly imagine, in this country at all events, conditions are likely to arise in a central station where a 5-minute discharge of a battery—that is to say, a discharge of a battery at its 5-minute rate—is likely to be required, or if such circumstances did arise, I think they would last a considerably longer time than 5 minutes and that the inevitable shut-down would only be postponed for a very short time. I should be inclined to say that practically the 1-hour rate is the shortest rate of discharge at which it really pays to use a battery, and that if that can be exceeded a good deal of capital will have been spent in providing for conditions which are unlikely to arise. With regard to the question of regulating cells *versus* boosters, I was certainly under the impression, until a short time ago, that the booster was the best and most economical method of charging and discharging a battery—particularly discharging. But I was very much surprised to

Mr. Shawfield.

find, when I had the opportunity of going through the Berlin Electricity Works, that quite the contrary opinion appears to be held on the Continent generally. In very large battery installations in Berlin boosters are quite unknown except for the purpose of charging, and they are not used to a very large extent for that purpose as the batteries are frequently charged through a rotary converter or motor-generator run at what one may term an over-voltage. These regulating switches are really wonderful in their simplicity and certainty of operation. I happened to see one in service moving over several contacts when carrying a current of 4,000 amperes. The contacts looked quite on the small side, but there was not the slightest trace of sparking, and although this particular switch had been in service for seven or eight years, the contacts appeared to be absolutely new, and I was assured that no repairs had been done to the switch since it had been installed. With regard to the cost of regulating cells, it does not appear as if it was actually any higher than the cost of boosters. In the case of a battery giving 1,000 k.w. for three hours, that is, roughly, 4,000 amperes at 250 volts for a period of three hours, I was informed that the cost of a regulating switch and connections (which were quite short, as it was placed alongside the battery-room, and the connecting bars only had to come through the wall), delivered and erected, was £1,000. This switch was capable of dealing with the discharge of the battery at the 1-hour rate—that is, at 6,000 amperes. It was capable of being moved from end to end without damage and without what may be called any serious sparking with a current of 5,000 amperes. I think there is very little doubt that the efficiency to be obtained by the use of regulating switches is very much higher than it possibly is in the case of boosters, because, as Mr. Taylor shows in his paper, the units lost through all-day running of boosters really amounts to quite a good deal in the course of a year, and those units are wasted in the booster just at the time when they are the most expensive to produce, namely, at the time of peak load ; whereas a booster, although relatively small, when necessary for charging, is used at a time when the units cost the least, namely, in the valleys of the load, and in the small hours of the morning. The extent to which batteries are used by the Berlin Electricity Works is really startling as compared with our English practice. The figures given by Mr. Taylor in his paper are rather on the small side. I see they are stated on a 3-hour rating. I was informed that the capacity of the batteries installed at the various sub-stations in Berlin was 35,000 k.w. for two hours, and that in the case of a breakdown, they were capable of maintaining the whole supply of the city for period of two hours. I inquired the reason why they considered it necessary to make such very large provision in the way of batteries, and they said, in the first place, batteries were a considerable source of economy—coal is very expensive in Berlin—and that the considerable reduction in the peak which they were enabled to effect, reduced their standby losses in the boiler house very considerably; and, in the second place, they were under very heavy penalties to the local tramways, the underground

Mr. Shawfield.

railways, tubes, and also to the Municipality of Berlin in the event of any failure of supply, and, therefore, the batteries were very largely installed as an insurance against the possibility of their being mulcted in a very heavy bill for penalties. That is a state of affairs which does not very often occur in this country. I do not know of any case where a supply has to be given under penalties for failure other than the purely nominal penalties imposed by the Board of Trade. Therefore, I think batteries can only justify their existence in so far as they actually tend to reduce the cost of generating. There is no doubt they can be used with very great advantage in that direction, but the advantage is limited entirely to their use on a 2- or 3-hour rate, according to the size of the peak, and provision should not be made for dealing with heavier currents than that. With regard to the Exide cells, I wish Mr. Taylor had given some further details of those, as I understood him to say in his opening remarks that they were suitable only for emergency purposes, and not for regular use. If that is so, I do not quite see why he has apparently suggested their use for the first peak in Fig. 19. I take it that that peak is one of regular occurrence, and, therefore, the batteries would have to be used daily to meet it. Then, with regard to the figures which Mr. Taylor has sketched on the blackboard, I am afraid I have not been able to follow them. It would appear he makes the standing charges for 11,200 k.w. of steam plant at £43,500 per annum. Surely they should be something like half that amount. £3·89 per kilowatt per annum must represent an expenditure of over £30 per kilowatt, whereas a modern steam plant can surely be put down for a figure of £12 per kilowatt. I think, therefore, the comparison which he has made is really not quite accurate, and I shall be glad if he will amplify it.

Mr. Pearce.

Mr. S. L. PEARCE: As the author has referred in two or three places in his paper to the large battery which has been put down in Manchester, a few facts and figures relating to the first complete year of working will, I think, be of some interest. In the first place, I would like to correct the figure which appears at the top of page 394, that the coal bill has been reduced by some 25 per cent. That was true of three months in the summer of last year, but the average for the completed twelve months is 13 per cent. I will come back later on to the actual savings which have been made by the installation of this battery, but perhaps it would be well at first to describe in a few words its main features and functions. Originally, when installed, we intended to charge the battery up off the traction busbars, and to discharge it purely as a peak-load battery over our heavy winter lighting "peak." The capacity of the battery at the 1-hour rate is approximately 3,000 k.w. The arrangement of boosters I shall refer to later, but it is quite possible—and this perhaps meets a point which has been raised by previous speakers—to drive the booster motors off the traction busbars instead of the lighting busbars. This is of value when the traction and lighting peaks are not coincident. Although it was intended normally to charge the battery from the traction bars and to discharge

on the lighting, it is so arranged that both the charge and the discharge can be used entirely on the lighting system. The results of the year have shown that the greatest benefit and the most economical results are obtained by keeping it entirely on the lighting system. Possibly the conditions at Manchester are ideal for a battery of this capacity and for this use. We have the high-tension station at Stuart Street and the two direct-current city stations (which for all practical purposes may be considered as one) in Dickinson Street and Bloom Street, and the connecting link between the two systems is the large 3-phase sub-station installed at Dickinson Street. This gives a very flexible arrangement. For example, if we have very dark weather in the morning and take a more or less complete discharge out of the battery, owing to the fact that the Stuart Street load is dropped some 7,000 or 8,000 k.w between 12 noon and 2 p.m. (due to the large industrial works leaving off for dinner) it is quite possible to get a very good charge into the battery again at midday from the sub-station, and it is then available for the winter evening lighting peak.* So that the conditions for getting more than one discharge per day out of the battery are more or less ideal. Mr. Pearce.

With regard to the savings which I estimate we have effected during the first complete year of working, they are as follows: Dealing with the coal first, a reduction from 3·33 to 2·89 pounds per unit generated has resulted—that is, a reduction of 0·44 of a pound—which on the output of the city stations—namely, 30,000,000 units—accounts for £3,348. There are other savings in the works costs, which latter amount in all to 0·064 of a penny, comparing the year ending March 31, 1911, with the previous year, and which, as far as I can see, are wholly due to the battery. This reduction of 0·064d. on 30,000,000 accounts for £7,762. Altogether, after allowing for full capital charges on the battery, and for the full maintenance, there has been a saving on the first year of £3,041. That takes no account whatever of any saving on capital charges, and if it be admitted that this battery at the 1-hour rate can be fairly compared with steam plant at the Stuart Street station, plus high-tension mains, plus converting plant at Dickinson Street, we get these figures: £13 per kilowatt installed for the steam scheme, that is, steam plant plus high-tension mains, plus converting plant, which I put at £13 a kilowatt and £8 for the complete cost of the battery—that is, battery boosters, switchgear, cabling, housing, and everything complete. This shows a difference of £5 per kilowatt. Taking 8½ per cent. on the £5, and at the 3,000-k.w. rate over the 1-hour—viz., £15,000—that gives a further saving of £1,950. We have therefore a saving on running and fixed costs of, roughly, £3,000, and on capital charges a saving of £2,000, or a total of £5,000. That figure does not differ very materially from the hypothetical case worked out by Mr. Taylor on the board.

A few other particulars might be of interest. We estimated the

* The maximum charging rate for the battery is 6,000 amperes and the normal rate 4,000 amperes.

Mr. Pearce. daily steam plant load factor in the winter would be increased from 32 to 43½ per cent. due to the lopping-off of the peak. As an average, I think, the figure of 47 per cent. might be substituted for 43½, but on some days we have reached as high as 60 per cent.—that is the daily steam load factor. The "commercial" or "over-all" efficiency of the battery—that is to say, the efficiency after deducting all booster and battery losses—works out for the year at 71 per cent., which I think is a very fair figure. On page 416 the author refers to there being a sufficient gain in saving and standby losses of boilers and engines; in other words, that the coal saving is fully equal to that lost in the inefficiency of the battery. Mr. Shawfield also made a point of that. Our figures are as follows: The total units lost in the battery and lost in the boosters were, roughly, 700,000. The coal saved was £3,348, so that the lost battery units are covered four times over by the coal saving. With regard to this question of rapid discharge rates, perhaps the figures of the Tudor battery at Manchester might be of interest. These are the actual figures we have obtained in practice, and are not the manufacturers' figures. We got 8,400 amperes at the 1-hour rate, 13,000 at the ½-hour rate, and 17,000 for 5 minutes. On that question of the high-discharge rate for the short periods and the design of the switches, I can assure you that the satisfactory operation of these large switches, even for 17,000 amperes, makes one wonder how the Americans successfully deal with this 40,000-ampere rate of discharge which we have heard of to-night. With regard to the question of using the battery as standby or emergency, I entirely agree with the author's remarks on page 418, where he says: "It will not be found advisable to put in batteries exclusively for standby or emergency purposes." I am rather sorry to see that in Appendix III. Mr. Taylor seems somewhat to hedge on the point, and suggests that a double arrangement should be put in, "a standby" and "an ordinary battery," as shown on the curve on the wall. It seems to me that a battery which will be large enough, as a substitute for a peak load steam plant, to give that economy in working which makes it a sound commercial investment, has all the emergency qualities necessary for the purpose. I agree with the author when he suggests that for ordinary commercial purposes it is quite good enough to put in a battery to "buffer" the demand in foggy weather so as to give time to get away the steam plant. As a matter of fact, that is how we do use the battery. With regard to the booster equipments, I think the author, unconsciously perhaps, has done us an injustice. He speaks about the Manchester booster plant being insufficient for discharging the battery at "emergency" rates. That is not correct. As a matter of fact, the booster equipments are three in number, and, collectively when operated in parallel, they are sufficient to give a current corresponding to the 5-minute maximum discharge rate of the battery at maximum boost. We have divided the boosters up into three sets, partly because, as I have explained before, the battery was intended for traction working as well as lighting, in which case the two boosters in series are run off

the traction bars, or at times of discharging on heavy lighting peak the boosters are all paralleled. No difficulty is experienced with the series-parallel arrangement. Mr. Jenkin has already referred to that, and I do not propose further to labour the point; but it seems to me that that is quite easily arranged—in fact, the diagram of connections of the Manchester battery which has been published shows clearly the arrangement of the switches and busbars, and no complications whatever are introduced. It is quite easy to go from series to parallel without any complicated change-over switch such as Mr. Taylor puts forward in his paper. Mr. Pearce.

I am inclined to think, after carefully considering this paper, that the sub-division of the booster units in the manner in which we have done it is even preferable to the arrangement which the author puts forward. With the latter arrangement all one can stand to gain is the annual charges on extra capital expended on the booster plant, at the expense of additional losses when charging, and, seeing what an extremely important function of the battery the booster plant is, I think outlay on the booster is money exceedingly well spent. What is wanted is absolutely reliable and sufficient plant to enable the battery to discharge up to its greatest capacity. With regard to Fig. 15, that seems to me to be a purely hypothetical case, which is hardly likely to occur in actual practice. I suggest that a maximum discharge is always coupled with the question of maximum boost. There is another point which is of interest—at any rate to engineers in charge of local authorities' stations—namely, the question of loan periods granted for batteries. It is the practice of the Local Government Board to grant seven years. Seeing that battery makers are now perfectly willing to give maintenance periods, say, on an 8½ per cent. basis for fifteen years, I think, if the Local Government Board can see their way to extend that term, it would be a further inducement to local authorities to take up batteries.

Mr. A. H. SEABROOK: There is no doubt that Mr. Taylor's persistent advocacy of batteries, in season and out of season, has caused a number of supply people to look more closely into the question. It has had that effect upon me, and I have given a lot of time during the last eighteen months to this subject. We in St. Marylebone have a problem to get over during the next year, or the year after, of supplying an additional 3,000 k.w., which has to be carried about 2,800 yards from our generating station to our principal distributing centre. Our generating station is at St. John's Wood, on the Regent's Canal, and our principal load belt is a few hundred yards north of Oxford Street, from Marble Arch to Tottenham Court Road. Three-quarters of our output is required there. On going into figures for additional steam plant and cable capacity, I found the capital cost was £57,000, and the cost for a storage battery for 4,000 k.w., at the 1½-hour rate was £25,000 or £26,000. There is thus a big saving on capital, apart from the improvement of the plant load-factor station, and the undoubted economies which may be obtained, and which we know can be obtained from our present experience with the comparatively small Mr. Seabrook.

Mr. Seabrook.

batteries we are using at present. In connection with that, the point as to loan periods made by Mr. Pearce is most important. We have just entered into a twenty years' maintenance contract for batteries, and, if a twenty years' maintenance guarantee can be given by the makers, there is surely no reason why the loan should not be granted for that period. In addition to that, the scrap value of a battery is very much greater than the scrap value of ordinary electrical plant. The overall commercial efficiency (71 per cent.) mentioned by Mr. Pearce is rather startling to me, and I shall have to look into some of our figures. I have taken out the kilowatt-hour efficiency of our battery without booster loss for last year, and I found it amounted to 74 per cent. The overall efficiency, including boosters and everything, was 54 per cent. Did Mr. Pearce refer to the ampere-hour or the kilowatt-hour efficiency? [Mr. PEARCE: Commercial over-all efficiency in kilowatt-hours.] Then that figure of 71 per cent. is an exceedingly good figure. With regard to the author's remarks on regulating cells, I do not think they are to be passed over in favour of boosters quite as readily as the author does. It is interesting to hear from Mr. Shawfield that regulating cells are used in America and on the Continent to a considerable extent. On our two existing batteries in Marylebone we found that, owing to the watts required to discharge by means of boosters, we were justified in spending a considerable amount of money in putting in additional end cells, to do away with the boosters during discharge time on peak load. We shall in future, I hope, get some figures which will show an improvement on the overall battery efficiency of 54 per cent. According to the author, the capital cost of end cells as against capital cost of boosters does not amount to very much, but it would be interesting to know if any one has any figures as to the working efficiency in kilowatt-hours as between using boosters and using end cells. It is significant that during the last year or two battery makers have been prepared to extend their maintenance to regulating cells, which they would not do some six or seven years ago. I do not know whether the author can give any information with regard to the number of cells which can be lumped together for each step in regulating. We have tried some experiments, jumping three cells at a time, which has not had any effect on the pressure of distribution. There was no fluctuation in the light supply. There is another point in favour of end cells, namely, that they are more reliable than boosters. The booster is the weak point in the charge and discharge arrangement. The switchgear is much less complicated by using end cells, and the class of men to look after a sub-station need not be so intelligent.

Mr. Andrews

Mr. LEONARD ANDREWS: In reading through Mr. Taylor's paper, my attention was attracted by an apparent discrepancy between the first items in Tables B and C (page 410). The capital cost of the extra 1,540 k.w. of steam plant is given in Table A as being £19,500. Interest and sinking fund at 6½ per cent. on this sum amounts to £1,270, or £1,670 less than the amount the author has included in

Mr. Andrews.

Table C for standing charges on the steam plant. The author makes Mr. Porter and myself responsible for the higher figure by quoting from our paper of two years ago on gas engines,* but I can find no justification in that paper for the figure quoted of £1·91 per kilowatt of maximum demand, which I agree with Mr. Shawfield appears to be much too high. I conclude that the author arrived at this figure by adding to the 6½ per cent. on the capital cost of the 1,540 k.w. of plant, 25 per cent. for additional standby plant, and a *pro rata* charge for increased labour and repairs. [Mr. TAYLOR: The details of that £1·91 are given above Fig. 23. Interest and sinking fund at 6½ per cent. £1·09, repairs 0·5, labour 0·32, total £1·91.] I had noticed these details, but 6½ per cent. on £19,500 only amounts to £0·877 per kilowatt, which led me to conclude that to arrive at the £1·09 per kilowatt Mr. Taylor must have included the interest and sinking fund charges on 25 per cent. of standby plant, which is probably quite justifiable. I contend, however, that it is altogether erroneous to assume that the extra labour and repairs will be directly proportional to the maximum demand upon the generating plant. If, for instance, the labour and repairs on an 8,000-k.w. steam plant amounted to £5,600—the figure given in the revised estimate contained in the reply to the discussion on our paper referred to—and the maximum demand on the steam plant was reduced to 6,500 k.w. by carrying 1,500 k.w. of the peak load on batteries, I am of opinion that the maximum reduction it would be reasonable to expect on the labour and repairs item would be £350 per annum. I consider therefore, that the standing charges on the steam plant should not be taken as being higher than—

	£
6½ per cent on £19,500	1,270
+ 25 per cent. extra standby	318
Extra labour and repairs	350
	1,938

Or £1·26 per kilowatt of maximum demand instead of £1·91.

With this amendment, and accepting Mr. Taylor's figures for the other items, I consider that the correct total fixed and running charges for the generating plant should be:—

	Fixed Charge per Kilowatt Maximum Demand.	Running Charge per Kilowatt-hour.
	£	d.
For steam plant	3·20	0·2210
For gas plant	2·98	0·0825

* *Proceedings of the Institution of Electrical Engineers*, vol. 43, p. 3, 1909.

Mr. Andrews.

These figures still show that a very substantial saving will be effected by installing batteries to deal with the peak load, as recommended by the author. In the general principal of attacking the standby losses as being the most vulnerable spot in modern power station costs, I am entirely in agreement with Mr. Taylor, and his recommendation of combining batteries with steam, gas, or oil engines, as local conditions may dictate, appears to be quite the most promising method of dealing with the difficulty. That standby losses are responsible for a very large proportion of the operating charges of a modern generating plant every one agrees, though opinions differ as to the extent of such losses. Taking the banking of boilers and radiation losses alone, we gave in our paper a figure which corresponded to 0·89 tons of coal per annum per kilowatt of maximum demand, and in the discussion on that paper Mr. Pearce gave results of some tests at Manchester, which appeared to confirm our figure; on the other hand, Mr. S. Donkin quoted results of a 16½-hour test, which showed a consumption equivalent to 0·2 ton of coal per annum per kilowatt of maximum demand. These conclusions are all based on comparatively short trials made under test conditions, and may therefore be misleading when applied to actual working conditions over long periods. On my way through Canada a few months ago, I visited a plant where a battery of boilers was kept under steam for the sole purpose of serving (in conjunction with two 2,000-k.w. steam turbo-generators) as a standby to a hydro-electric supply. I was interested to learn that the banking and radiation losses of this plant amounted to approximately 3,600 tons of coal per annum, or 0·9 ton per kilowatt of maximum demand.

Mr. Duncan.

Mr. E. MACGREGOR DUNCAN: Mr. Pearce has mentioned his battery at Manchester, and says he discharges twice a day. I should like to know whether the makers allow him to discharge the batteries under a maintenance contract once, twice, or oftener a day, or do they restrict him to any limited number of discharges?

Mr. Cooper.

Mr. W. R. COOPER (*communicated*): Mr. Taylor's paper, coupled with the remarks of speakers in the discussion, emphasises the importance of working a battery for dealing with peak loads under the most economical conditions, not merely in combination with boosters, but also in regard to the batteries alone. The extremely fine figure of 71 per cent. given by Mr. Pearce for the over-all efficiency at Manchester, including boosters, compared with the much lower figure of 54 per cent. given by Mr. Seabrook for the battery at St. Marylebone, leads me to think that a good deal must depend upon the conditions under which the battery is worked apart from the boosters. This view is borne out by the fact that a buffer battery works more efficiently than a battery used under the usual lighting conditions. Mr. J. S. Highfield* obtained a figure of 84 per cent. for the former and 74 per cent. for the latter. The higher efficiency of the buffer battery is doubtless due to the small range of the charge and discharge curves

* *Proceedings of the Institution of Electrical Engineers*, vol. 30, p. 1070, 1901.

over which working mostly takes place. The most efficient result is likely to be obtained by working over what may be termed the flat parts of the normal charge and discharge curves as far as possible, so as to approach buffer battery conditions. It would be interesting if Mr. Pearce would give full particulars of the method of working at Manchester, so as to show whether these conditions are approached. Mr. Cooper.

Mr. A. M. TAYLOR (*in reply*): Mr. Jenkin remarks that "if we increase the number of the cells sufficiently, the whole of the cell output is available on the busbars," but I must entirely disagree with this. Particularly is this not the case when very rapid rates of discharge from the cells are comtemplated. Let us, however, consider first the 1-hour rate of discharge. Referring to Fig. 4, it will be noticed that, for a 1-hour discharge, 303 cells are required. Of these cells, Nos. 1–275 are fully discharged, Nos. 276–285 are discharged on the average for $\frac{7}{8}$ hour, Nos. 286–290 for $\frac{5}{8}$ hour, Nos. 291–295 for $\frac{3}{8}$ hour, Nos. 296–297 for $\frac{3}{16}$ hour, Nos. 298–300 for $\frac{1}{8}$ hour, and Nos. 301–303 for $\frac{1}{16}$ hour. The battery is thus only equivalent at the peak of the load to 290 cells; in other words, there is 4 per cent. of the current locked up in the cells. The case would, of course, be much worse if we took the 365 cells (see Fig. 4). Mr. Taylor.

Now, with the booster arrangement some 3 per cent. of the battery current is, with the most efficient arrangement, taken up on the average by the booster motor during the discharge; but out of this energy some 2 per cent. is returned to the battery circuit by the booster, the actual loss therefore being only 1 per cent. as against the 4 per cent. of ampere-hours locked up in the regulating cells. There is therefore a net gain of 3 per cent. in the size of the battery by the employment of boosters; with the additional very great advantage that the whole of the cells are equally charged and discharged.

It has been stated in the discussion that the battery makers are prepared to undertake the maintenance at the same rates where regulating cells are employed. It must, however, be remembered that the additional labour and inspection involved in attending to these regulating cells falls entirely on the central station and not on the battery makers; and the labour and inspection charges on a battery installation may become quite considerable and can only be kept down by reducing all items connected with battery maintenance to a minimum. The author knows of two batteries of equal output in the same station, and worked under the same conditions, in which the labour charges were respectively £150 and £450 per annum. These sums were exclusive of the battery manufucturers' maintenance contract. In cases where the batteries are likely to be discharged at higher rates than the 1-hour rate, the above remarks apply with increased force, there being more regulating cells and greater inequality of discharge among them. It may not be out of place to remark that Fig. 9 does not represent the limit of economy attainable before changing to the arrangements shown in Figs. 15, 16, and 17. Mr. Jenkin has apparently taken Fig. 14 to refer to the curves given in Fig. 15, but this is wrong; Fig. 14 being

Mr. Taylor. suitable either for the curves of Fig. 13, or the intermediate higher limit of economy just referred to. He has also misunderstood the employment of regulating cells as shown in Fig. 9. The cells here shown are not really "regulating cells" at all, but "floating" cells. Their function is merely to prevent the battery discharging into the busbars during that part of the day when no discharge is being taken out of the battery and when, for purposes of economy, the main boosters are shut down. The battery, to be available at all times as a standby, must, of course, be kept floating on the busbars. In addition to their employment for "floating purposes," however, these cells also serve the function of compensating for any heavy out-of-balance load, which the static balancer is unable to do. Mr. Jenkin's proposed arrangement of combined regulating cells and boosters is extremely ingenious. As the author understands Mr. Jenkin's proposal, he keeps the current in the regulating switch branch to zero during charge, and during discharge he runs the booster as an inverted motor in such a way as to cause every cell to give the same current. Without going into this proposal in detail the author believes it will be found impracticable to make the charge and discharge ampere-hours of the regulating cells balance out in this happy way, with the result that we are no better off than if we had regulating cells alone. Another difficulty that will probably be incurred is the following: Where a battery is used partly as a standby, it is desirable that at the end of the peak discharge there should still be, perhaps, half of its discharge left in the battery. Now, according to the time of year this will be a continually varying quantity, and it would seem that Mr. Jenkin's booster arrangements could not possibly be accommodated to suit the cells under all conditions; whereas if we rigidly keep the boosters in series with the cells the acme of simplicity is attained. Then, as to the question of the regulating switch being suitable for taking unexpected emergency discharge rates, it has yet to be proved that a regulating switch with its many heavy connections will not be very expensive when it has to be designed to move over a very large number of contacts and to carry, while moving over the contacts, currents approaching the 5-minute rate of the battery discharge. These conditions will, I believe, be more simply met by an automatic switch which short circuits the booster busbars (where the boosters are in series with the battery), and at the same time wipes out the booster field and opens the circuit of the booster motor. The money to be spent is thus restricted to dealing with a single pair of contacts instead of having to deal with the same current perhaps 30 or 40 times over.

Mr. Shawfield complains that the paper does not deal sufficiently with the coal economics. On this point I may explain that this is because I am in substantial agreement with Mr. Andrews' treatment of the the subject in his paper on "The Use of Gas Engines for Generating Electric Power." * Mr. Andrews there adopts a method of calculation

* *Proceedings of the Institution of Electrical Engineers*, vol. 43, p. 3, 1909.

Mr. Taylor.

which lends itself to any load factor and any station. In my reply to Mr. Andrews, Mr. Shawfield will find further particulars as to boiler standby losses. I do not agree with Mr. Shawfield that there is no advantage in being able to discharge the battery at higher rates than the 1-hour rate. It seems to me that this is entirely a matter of the proportion of the station output borne by the battery at its 1-hour rate. If, in a station having a 20,000-k.w. maximum demand, batteries are only put in for, say, 4,000 k.w. for 1 hour, it might be exceedingly inconvenient to be unable, for, say, ½ hour, to increase this to 12,000 k.w. If, on the other hand, they were put in for 8,000 k.w. for 1 hour, it would be equally useful if they could be employed at a correspondingly higher rate for only half an hour. I know of a large station in this country where probably this would have just saved a serious breakdown. Mr. Shawfield questions my total of £43,500 for the fixed charges for a station of 11,200-k.w. maximum demand, as in Fig. 19. The figure of £3·89 per kilowatt on which it is based is given in detail in Table C of the paper, and consists of the following items: Interest, etc., sinking fund, labour, and repairs at generating station = £1·91 per kilowatt; rates, taxes, and insurance = £0·25 per kilowatt; "standby coal" = £0·79 per kilowatt; interest, etc., on E.H.T. mains, rotaries, etc. = £0·42 per kilowatt; repairs on E.H.T. mains and in substations = £0·195 per kilowatt; labour in sub-stations = £0·097 per kilowatt. As regards the item £1·91, I must refer Mr. Shawfield to Mr. Andrews' paper (see also my reply to Mr. Andrews, *loc. cit.*). The item for rates, taxes, and insurance is based on the assumption that if the batteries are put down only at the substations and are paid for out of revenue, the observed maximum demanded at the generating station would remain stationary, and there would be no justification for an increased rating (see also article in the *Electrician* for December 4, 1907, for further consideration of this point *). In taking only £0·25 per kilowatt per annum for rates and taxes, I am taking only one-quarter of the figure obtained upon the whole undertaking at Manchester. The standby coal is, no doubt, debateable; but here again the author is only following Mr. Andrews, whose figures do not greatly disagree from some obtained by a different method (see *Electrician, loc. cit.*). Mr. Shawfield is evidently thinking only of the plant at the generating station, whereas I am considering the cost of delivering direct current to the sub-station bars 1 mile away, which adds another £7 per kilowatt to the capital cost, as shown in Table B. Mr. Andrews considers that I have not quoted him correctly. My figures were, however, taken from Mr. Andrews' paper, and I have since verified the items challenged, and find them quite correct. The figure of £1·91 per kilowatt is deducible directly from Mr. Andrews' own figures. If we add together £2,590 (labour), £4,000 (repairs), and £9,050 (interest, etc., on capital), and divide by 8,000, k.w. we get £1·91 per kilowatt per annum. The £9,050 is obtained by taking 6½ per cent. on Mr. Andrews' own figures of £13·95 per kilowatt. The other

* *Electrician*, vol. 62, p. 305, 1908.

Mr. Taylor. two figures are his own.* The way in which I looked at the extra cost of labour and repairs was quite different to what Mr. Andrews suggests. What I contend is, that if, in a station with a steady developing load, we stop putting in steam plant for three or four years and put in batteries instead, we make savings in labour and repairs which are nearly proportional to the reduction in the maximum demand from the demand which would otherwise have obtained. Some time ago I published figures † which showed that, at Manchester, the charges for labour and repairs were a nearly constant figure per kilowatt during the growth of the station demand from 10,000 to 15,000 k.w.; the first item, in fact, rising quite materially above mere proportionality. The charges for rates and taxes kept virtually constant over a very much greater range—actually up to 30,000 k.w. If we think only of the diminution in labour and repair charges caused by putting in batteries (to the small value of 1,450 k.w.) in a station already equipped with the full amount of steam plant to meet its load without any help from the batteries, no doubt Mr. Andrews is right. But, supposing that the station has now a maximum demand, say, 10,000 k.w., and that we now put in batteries to deal with another 5,000 k.w., would it not be right, in view of the Manchester experience, to assume that the labour and other fixed charges on those extra 5,000 k.w. would have been proportional to the kilowatts, and, therefore, would have been entirely saved by employing batteries? It seems to me that it would.

Mr. Andrews accounts for £1,625 out of my £2,940; but if he will take labour and repairs at his own figure of £0·824 per kilowatt he will account for another £1,270, leaving only £45 unaccounted for, which is negligible. Mr. Andrews, in his paper on "Gas Engines," made the "standby engine-hours" and the "banked boiler-hours" account for 5,140 and 3,330 tons of coal respectively, representing money values of £3,850 and £2,485 respectively. This works out at £0·79 per kilowatt of maximum demand per annum, which is the figure quoted by the author in Table C of his paper. In the notes against Fig. 23 of his paper, however, he has, to be safe, taken only two-thirds of this amount, or £0·52 per kilowatt per annum. Some four years ago, when investigating this subject, I obtained a figure equalling the above £0·79 per kilowatt by assuming that the true "running cost for coal during the year should only be that which might have been expected in generating the units turned out during the year under "test" conditions, and that the difference was due solely to standby losses in engines and boilers. It is interesting that Mr. Andrews' figure, obtained in quite a different way, should agree quite closely with the figure so obtained.

I am fully in accordance with Mr. Pearce's remarks, except that I cannot agree with his statement that the boosters at Manchester are put in on the best possible lines. But his arrangements, at the date of carrying out his installation, were undoubtedly the best in the market. As regards my remark about the Manchester boosters being inadequate

* *Proceedings of the Institution of Electrical Engineers*, vol. 43, p. 30, 1910.
† Ibid., vol. 44, p. 647, 1910.

Mr. Taylor.

for discharging the battery at emergency rates, I desire to withdraw this; though the remark was qualified by the phrase "or to draw upon spares," which appears to be correct. At the same time, I think I could undertake to halve the cost of Mr. Pearce's boosters, and so save about £1,000 initial outlay, and also save some £50 per annum in booster losses. I regret having to dissent from Mr. Pearce when he speaks of the "series-parallel arrangement" at Manchester being so successful. He has *no series-parallel arrangement whatever* on his lighting side (according to his published diagrams of connections), and only a "double-series" arrangement on the traction side. This latter feature was quite an accident, and merely got introduced owing to the fact

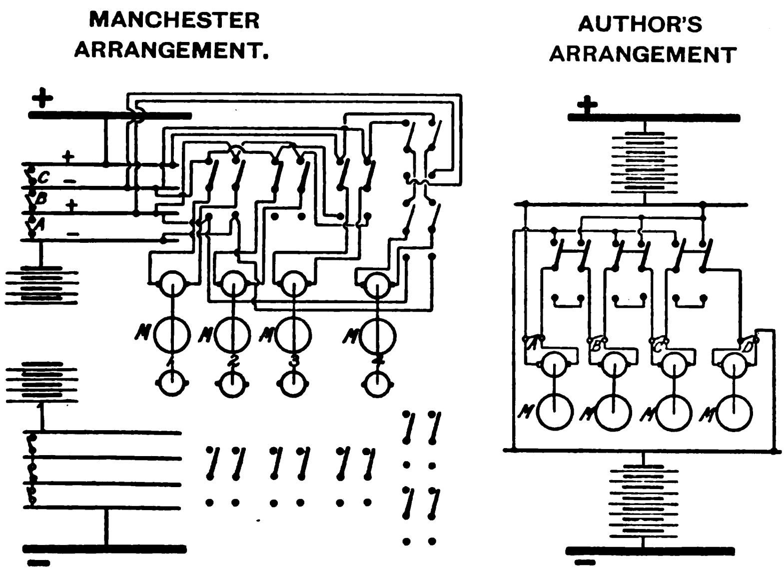


Fig. B.

that, as Mr. Pearce wanted the same battery to do duty for busbars whose respective pressures were 450 volts and 525 volts, the boost on discharge had perforce to be doubled on the traction side. The accompanying diagram (Fig. B) is given in order to illustrate the clumsiness of the "multi-busbar" switching method, where three boosters are working and one is a spare, in the (almost universal) case where it is desirable to keep a connection with the neutral wire of the 3-wire system, as compared with the method proposed in the present paper. Fig. B shows the Manchester method on the left-hand side. It will be seen that this involves four double-ended boosters, whereas my arrangement involves only single-ended ones; it also involves 8 busbars, each equal to the full current output of the battery, 8 short-circuiting

Mr. Taylor. switches, each equal to the full current output, with 2 double-pole single-throw and 8 double-pole double-throw switches, each equal to the output of one booster; whereas the author's proposal only involves 2 busbars and 4 short-circuiting switches, each of only the section for one booster, and 3 double-pole double-throw switches. Even if we sacrifice the neutral connection, Mr. Pearce's scheme involves 4 busbars, 4 short-circuiting switches of full section (8,000/17,000 amperes), 1 double-pole single-throw, and 4 double-pole double-throw switches. It is no easy matter to accommodate these heavy busbars, and 4 switches each for 8,000/17,000 amperes will cost more than double, if not treble, what the same number of switches for 2,000/4,400 amperes would cost. As regards complication, I submit that my method is the simpler. It is, however, quite easy to keep the board simple when only two boosters are employed in series, as at Manchester. It is interesting to hear from Mr. Pearce that his saving in coal pays four times over for the losses due to the inefficiency of the battery. The author in his paper of 1908* before the Incorporated Municipal Electrical Association claimed to demonstrate that this "inefficiency" scare was groundless, and to show that there should be a decided net saving in coal. It has, however, been left to Mr. Pearce's enterprise to demonstrate in practice that this is so, when batteries are used in a really serious way. With regard to Mr. Pearce's remarks on "the additional loss when charging," I do not propose to labour this point, as I think it is demonstrable that there are no additional losses when charging, but, on the other hand, a great gain; and I believe that Mr. Pearce will admit this on fuller consideration. If correct, it would at once discredit regulating cells, on the ground of economy alone.

Mr. Seabrook will find his remarks as to regulating cells dealt with quite fully in my reply to Mr. Jenkin. With regard to Mr. Seabrook's inquiry as to the inefficiency in kilowatt-hours of boosters as against end-cells, I would submit that the question is not here altogether one of efficiency. An unnecessary investment in cells, which take up the attendants' time and also incur maintenance charges out of all proportion to the work done by them, may be quite as inefficient as a booster wasting a definite number of kilowatt-hours.

I am of opinion that boosters will be found increasingly useful as the batteries are used on the higher discharge rates, and regulating cells where the reverse is the case. In any case, either "floating" cells or a "bucking" booster (which can be kept very small) should be used for the periods when the battery has to "float" on the busbars. From a consideration of the charge and discharge curves I feel satisfied that the losses in the boosters, on the triple-series method, will not be more than 1 per cent. of the output on the discharge and another 2 or 3 per cent. on that of the charge, giving a booster efficiency of 96/97 per cent. Regarding the grouping of end-cells for switching purposes, the New York "Exide" batteries employ 32 single-cell and 12 triple-cell con-

* *The Electrician*, vol. 61, p. 480, 1908.

tacts, and the other 82 cells in the main battery; *i.e.*, 150 cells in all, across the outers of the 3-wire system. The arrangement gives one cell per switch-point round about the "floating"-point, and more rapid cutting-in towards the end of an emergency discharge. Good results are stated to be obtained with this arrangement. I understand that a uniform distribution of two cells per point is common practice in Germany. **Mr. Taylor.**

Proceedings of the Five Hundred and Twenty-second Ordinary General Meeting of the Institution of Electrical Engineers, held on Thursday, May 4, 1911—Mr. S. Z. de Ferranti, President, in the chair.

The minutes of the Ordinary General Meeting, held on April 27, 1911, were taken as read, and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Hall.

The following list of transfers was announced as having been approved by the Council :—

TRANSFERS.

From the class of Associate Members to that of Members :—

Frederick Black.
Wm. Gregory Chace.
Benjamin John Day.
Sidney B. Haslam.
Joseph Alex. Panton.
Edwin Hartree Rayner.

From the class of Associates to that of Members :—

Edward Ashmore Thompson.

From the class of Associates to that of Associate Members :—

Charles Bluthner Lessner.

From the class of Students to that of Associate Members :—

Richard Amberton.
Alexander C. Anderson.
Moritz Ignatz Bergl.
William Dundas Fox.
Peter Harris.
Hedley Large.
Arthur Lockwood.
Murdoch E. Macdonald.
James Meredith.
Charles Wm. G. Nelson.
Wm. Arnold Prescott.
Fred. Charles Purvis.
Harry Kramer Trechmann.
Reginald D. Wolfgang.

From the class of Students to that of Associates :—

Charles Graham Wells.

Messrs. H. H. Harrison and A. Green were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected:—

ELECTIONS.

As Member.

George Stephen Corlett.

As Associate Member.

Ernest Hall.

As Associates.

A. Bruce Anderson.
Harold Ashton.
Archibald Bursill.
William Bellad Ellis.
Alfred Edwin Hall.
James Cecil J. Johnston.
Hawthorne McKenzie Millar.
Alexander Richard Newman.
Percival Herbert Nye.
Edwin Hallett Winton.

As Students.

Grey Beaumont.
William Biggam.
Jageshwar Dayal.
Norman Rausch de Pomeroy.
Harry Vincent Henniker.
Frank Edgar Hill.
Henry Meggeson Jordison.
William W. Kerr.
Alexander Simpson MacWhirter.
James Oliphant.
Joseph Parker.
Charles Joseph Polden.
Walter Smith.
Percy George Spary.
William Witcomb Stainer.
Reginald Victor Stone.
Charles Stewart Williams.

The following paper, "Practical Aspects of Printing Telegraphy," by Mr. Donald Murray, M.A. (page 450), was read and discussed.

PRACTICAL ASPECTS OF PRINTING TELEGRAPHY.

By DONALD MURRAY, M.A., Member.

Paper first received January 17th; received in final form February 17, 1911. *Read before the* INSTITUTION *May* 4, 1911.)

In a paper read before the Institution in 1905,* under the title of "Setting Type by Telegraph," an outline was given for the first time of the theoretical aspects of printing telegraphy. The author has always had in view the preparation of a second paper dealing with printing telegraphy from a practical point of view, especially in regard to the obstacles that stand, or formerly stood, in the way of the general introduction of printing telegraphs. The subject does not appear to have been treated in any publication, and as it is probable that these obstacles will, in time, acquire historic interest for telegraph engineers, it seems desirable to have them put carefully and fully on record. During the past ten years the author has had unique experience of these difficulties in New York, Boston, London, Birmingham, Manchester, Edinburgh, Berlin, Hamburg, Vienna, Stockholm, Gothenburg, St. Petersburg, and Moscow, and the following paper embodies the results of that experience.

SUMMARY.

The paper is divided into three parts, as follows: Part I., dealing generally with the field for printing telegraphy; Part II., dealing with the practical difficulties in the way of printing telegraphy; Part III., describing some printing telegraph apparatus designed to overcome these difficulties.

PART I. discusses the field for printing telegraphy, and it is shown that there is little scope at present for printing telegraphs in wireless work, in railway telegraph traffic, or on long ocean cables. Their use is chiefly in connection with land telegraph lines between centres of population, and it is shown that printing telegraphs will, in the future, perform a very important service in assisting the co-operation between telegraph and telephone. It is admitted that for transmission of intelligence over short distances the telephone stands unrivalled; but it is contended that for the transmission of intelligence over considerable distances the most efficient arrangement is a combination of

* *Journal of the Institution of Electrical Engineers*, vol. 34, p. 555, 1905

the telephone and telegraph, the telephone acting as the collector and distributor for long telegraph lines. The reason is that the cost of long telephone lines is very great, while the labour cost of a telephone conversation is extremely small and the time-saving is great. With the telegraph, on the other hand, the cost of the line is less than one-quarter of the cost of a telephone line; but the telegraph labour cost is very heavy and there is much loss of time. By co-operation between the telegraph and telephone the advantage of the cheap telegraph line is combined with the advantage of the low labour cost and time-saving of the telephone. It is therefore contended that economic necessity will in future lead to a great increase in telephone-telegrams, or, as the British Post Office already calls them, "phonograms." Printing telegraphs will form essential links in the telephone-telegraph network, because printing telegraphs are the only means by which the carrying capacity of telegraph lines can be greatly increased and the labour cost at the same time decreased.

PART II. is a long and detailed account of the difficulties that have been encountered in connection with the development and practical application of printing telegraphs. With the idea of forming an historical record of these difficulties, they have been fully and minutely described. It is pointed out in the first place that the saving of labour by the use of printing telegraphs cannot in the nature of things be very great; but that there is reasonable ground for expecting to save from 25 to 50 per cent. in labour compared with the Morse key and sounder. The obstacles encountered in dealing with both commercial and press messages are discussed.

The difficulties in the way of making a copy for record of telegrams delivered are explained, and it is pointed out that wet-press copying is the only practical method of retaining copies of telegraph messages when printing telegraphs are used. The necessity for keeping copies of telegrams at all is not quite obvious.

When page-printing telegraphs are used a change is necessary in the telegraph forms used by various Administrations. There are two kinds of telegraph messages, those sent from city A to be delivered in city B, and those sent from city A to be retransmitted in city B to city C. In city B nearly all telegraph administrations use two different kinds of telegraph forms to distinguish these two kinds of messages. For a page-printing telegraph only one form for both kinds of messages is possible.

Numbering telegraph messages presented some difficulties in England when the Murray automatic printing telegraph system was introduced.

Counting the number of words in telegrams is a serious burden. There are so many Siamese twin words that are neither one nor two, that counting words is difficult, and the necessity for careful checking and counting considerably diminishes the number of telegrams that it is possible to transmit per hour. It also increases the labour cost. If it were possible to charge for telegrams in some way by time as

in the case of the telephone, instead of by words, a lot of delay and labour would be saved.

Errors in telegrams, due to the telegraph line, to the telegraph machinery, and to the human operator impose very serious limitations on the time and labour saving possible with printing telegraphs.

The variety of telegraph messages and the irregularity in the flow of telegraph traffic also greatly reduce the possible time and labour saving.

Traffic arrangements and hours of duty of operators are necessarily of a very complicated character in the case of large telegraph administrations, and the introduction of printing telegraphs leads to considerable variation of these arrangements. It is most difficult to introduce changes in the daily routine of large numbers of human beings. Of course, in the case of France, Germany, and other countries on the Continent of Europe, where the Hughes has been largely employed for more than a quarter of a century, such difficulties have long since adjusted themselves. It is in the Morse key and sounder countries that the introduction of printing telegraphs necessitates some changes of routine.

International telegraph traffic presents special difficulties because of the division of authority and differences in habits and ideas and customs and differences in language.

Alphabetical troubles are not the least that printing telegraph inventors have to encounter. Each country requires some variation in the telegraphic alphabet, and it appears to be a physical impossibility to devise a printing telegraph that will suit all languages. A curious illustration of this alphabetical difficulty is the confusion that exists in Great Britain through the use of the oblique stroke both for money and fractions. 3/8 may be read as 3s. 8d. or as $\frac{3}{8}$. This confusion has led to monetary loss.

Code and cipher messages are the despair of telegraph administrations, but on the whole a good printing telegraph can handle such messages with less risk of error than the Morse key and sounder, and at least as expeditiously if proper methods are used. The essential condition is careful training of operators in working on typewriter keyboards without looking at the keys.

The use of envelopes and the addressing of telegrams present difficulties in the case of page-printing telegraphs. On the Continent of Europe envelopes are not used, and the telegrams have to be folded up in special ways varying with each administration. The printing of the messages must suit these methods of folding. This requirement is hard to fulfil in the case of a page-printing telegraph.

Finally, there are mechanical difficulties of construction. Printing telegraph machines belong to a theoretically bad group of mechanisms, in which the majority of the actions are striking instead of sliding or rolling, and it is only by close attention to details that success has been achieved.

Part III. gives a brief general description of the Murray automatic

system and a more extended description of the new Murray multiplex system as an illustration of some methods by which it has been attempted to save time, line, and labour in telegraphy and to overcome the difficulties enumerated in Part II.

PART I.

INTRODUCTION.

For any distance exceeding a few miles, our sole physical means of transmitting intelligence at a speed greater than by letter post is the electric wave. There are only two possible methods of using the electric wave for signalling—namely, the guided wave along a wire (ordinary telegraph and telephone) and the unguided wave (light signals and "wireless"). Electric waves in the form of light have so many limitations that they are of no importance from the printing telegraph point of view, except as a local means of printing, and further reference to them in this paper is not required. As the longer waves used in wireless telegraphy have a much greater range on the surface of the earth, no doubt in time wireless printing telegraphy will receive more or less attention, but it will not be of much importance, in this generation at any rate, because there cannot be any saving of line or line maintenance when there is no line. Any saving of labour that might be effected by wireless printing telegraphy is of trifling importance, because the wireless operator has to be in attendance in any case, and the speed of signalling is low. It is in supermarine telegraphy, where it is impossible to use the guided electric wave, that wireless telegraphy has its great field, and in nearly all cases of ship telegraphy the work can be dealt with easily by one operator. Also the Morse key is the quickest means of communication (excepting the telephone). Hence in most wireless work, printing telegraphy would save neither line, labour, nor time. There is nothing else that it can save. Under such circumstances the extra cost and complexity of printing telegraphs would not be justified. Possibly for rapid transmission of wireless messages between two fixed centres, printing telegraphs may come into use, but not in the immediate future. Wireless printing telegraphy therefore does not require consideration, and we may confine ourselves to the guided electric wave as used with the telephone and telegraph, including underground and submarine cables. Transmission of intelligence so far as the guided electric wave is concerned may be classified into short-distance and long-distance telephone traffic and short-distance and long-distance telegraph traffic. Further subdivisions of telegraph work, which overlap more or less, are land traffic, cable traffic, news work, commercial and other ordinary short telegrams, railway work, and the stock ticker and urban news service.

It is not necessary in this paper to touch on the local transmission of intelligence over distances more or less within city limits. For this

purpose the telephone and stock-ticker and telautograph have reached a high state of development and form a group by themselves. The difficulties they have had to face have been almost entirely mechanical. No serious obstacles have been presented by the nature of the traffic they have to deal with. Hence they will only concern us in so far as they serve as feeders to the general telegraph and telephone network between centres of population.

For railway work printing telegraphs have hardly been employed at all up to the present, and as the telephone is gradually displacing the telegraph for most railway work in America, and therefore no doubt in time in other countries also, printing telegraphy does not appear to have any extensive possibilities in conjunction with railways, and it therefore does not require special discussion at present. In time, printing telegraphy will probably play a considerable part in connection with ocean cables, but up to the present hardly anything has been done in this direction, because the conditions to be fulfilled are extremely complicated. In the first place, there cannot at present be any line saving, because ocean cables are already utilised up to their full capacity. It will be possible to effect a slight saving of time and some saving of labour, but the apparatus will necessarily be of a very delicate and intricate character. The expenditure will necessarily be heavy, and the saving will not be more than about £300 or £400 a year on each cable, at each end. The saving of time is more important on the Atlantic cables, and reliable apparatus that would print messages in Roman type direct from the cable signals would be attractive to the cable companies in places like New York, where the cables terminate in Wall Street, the business heart of the city. Meanwhile the attention of printing telegraph inventors is absorbed by land line work, and printing telegraphs for ocean cables have to wait. The application of printing telegraphs to news work will be dealt with later on.

So far as the present position of printing telegraphs is concerned, the Hughes tape printer carries the bulk of the telegraph traffic on the Continent of Europe, and it has done so for nearly half a century, about 3,000 Hughes instruments being now in use. Most of the telegraph traffic between Great Britain and the Continent is also carried by the Hughes, but this machine is only employed outside of Europe to a very slight extent. During the past thirty years the Baudot system, which may be described as a multiplied Hughes tape printer, has been developed and extended in France until all the telegraph lines of any importance are equipped with it. During recent years it has also made considerable progress in Italy, Brazil, India, and Russia. In Russia it is quite extensively used, most of the leading towns in European Russia being connected by it. It has likewise secured some foothold in most other European countries, Paris being linked up by it to nearly all the capitals of Europe.

Great Britain has proceeded in very leisurely fashion, and, so far, has only coquetted with printing telegraphy, more or less prolonged

flirtations having been carried on by the British Post Office with the Hughes and Baudot, the Buckingham, the Murray automatic, the Siemens and Halske, and several other systems. The latest arrival, the Murray multiplex, may be described as the child of the British Post Office, it having been developed with the assistance of that Institution. The Murray automatic system has made most progress up to the present in Germany. It has also secured a foothold in Russia, Sweden, and Norway. It is in regular commercial use between Hamburg and Berlin, Berlin and Frankfurt, Hamburg and Frankfurt, Berlin and St. Petersburg, St. Petersburg and Omsk in Siberia (about 2,400 miles with three repeating stations), Stockholm and Gothenburg, Kristiania and Bergen. A new installation with all the latest improvements is being established between London and Dublin. For various reasons, however, the use of the Murray automatic system is limited to long lines and underground cables, and there is consequently not a very wide field for it, especially in comparatively small countries like Great Britain. The Murray multiplex, on the other hand, is very well adapted for moderate distances, but it has not yet had time to come into extensive use. In the United States the Buckingham system was developed under the auspices of the Western Union Telegraph Company, and some 60 circuits are now equipped with the Buckingham system as improved by Barclay.

Printing telegraph inventors are still busy increasing the height of the printing telegraph scrap pile, as they have been doing for fifty years, especially in America, but the substantial results over the whole wide world are summarised in the foregoing paragraphs. These results are neither extensive nor brilliant, and it is an actual fact that less than £1,000,000 sterling would cover the value of all the printing telegraph machinery on the face of the earth to-day. This is the outcome of fifty years of constant labour by scores of inventors. We have only to compare this with the gigantic extension of telephone apparatus all over the world in only a few years to realise that there must be some hampering circumstances, some peculiar difficulties and obstacles in the way of printing telegraphy, when we compare its stunted growth with the enormous progress of the sister art of telephony. It is the intention in this paper to give a full and detailed account of these peculiar obstacles and difficulties, and of the exceedingly complicated conditions with which printing telegraph systems have to comply.

For this purpose it is necessary first to get a clear, general view of the practical processes employed in the transmission of intelligence by the telephone and by the telegraph. In doing so we have to bear in mind that in the transmission of intelligence there are four economies of fundamental importance, namely :—

1. To save time.
2. To save labour.
3. To save line.
4. To save office equipment.

Everything turns on these four vital points. They are all more or less antagonistic economies. Time, for instance, can be saved by increasing labour cost or *vice versâ*. Good management is a question of balancing these economies against each other so as to secure the maximum result. Investigation shows that it is far more important to save time, labour, and line than to save office equipment. Heavy expenditure on office equipment in the shape of printing telegraph machinery is therefore one of the inevitable developments of the future. As will be seen presently also, the necessity for co-operation between the telegraph and telephone will compel development in the same direction. That the relation of the telephone to the telegraph has an important bearing in regard to printing telegraphs will be seen from the following considerations: In the case of the telephone the sender and receiver of a message are put in direct communication, and there is no intermediate labour whatever. This result, however, is only obtained over anything more than moderate distances by heavy expenditure on telephone lines. Two expensive copper wires are needed for the telephone in place of one cheap iron wire for the telegraph. The telephone line expenditure, in fact, is so heavy for long distances that beyond about 1,000 miles the cost becomes almost prohibitive. The theoretical reasons for the great differences between telegraphic and telephonic methods were given in the paper on "Setting Type by Telegraph," already referred to,* and it is only necessary here to deal with the practical aspects of the matter. In the case of the telephone there is no scope for machinery, so far as the actual transmission of the message is concerned, because there is no labour at all beyond speaking and listening. The cost of a telephone message over a short distance is therefore very small—2d. for about 200 words sent and 200 received in reply—and there is absolutely no delay or loss of time except in getting connected. Obviously the telephone saves enormously in time and labour, that is to say, in two out of the four vital elements of cost. It is this enormous economy that has led to the expenditure of such immense masses of capital in the extension of the telephone service all over the world. In the case of the telegraph the conditions are almost exactly opposite, and the telegraph at present is more or less crushed between the upper and nether millstones of the telephone and the letter post. It is only over long distances that the telegraph stands supreme, and it does so because of the very low cost of the telegraph line compared with the telephone line. The relative value of the telegraph increases and the relative value of the telephone decreases rapidly in proportion to the distance.

Let us take the case of a business man in London who wants to communicate with a man in Birmingham, a short distance of about 120 miles. If he telephones he gets direct communication in a few minutes and at no great cost. (There is, of course, often considerable delay in getting a trunk connection, but it is much less than the delay

* *Journal of the Institution of Electrical Engineers*, vol. 24, p. 555, 1905.

in getting a reply by telegram.) If he telegraphs he has first to dictate the telegram to a clerk, who writes it out and hands it to a message-boy, who takes it to the nearest telegraph office and hands it to a counter-clerk, who counts the number of words and collects payment. A messenger then takes it and puts it in a pneumatic tube, by which it goes to the London central telegraph office. Here a messenger takes it out of the tube and it goes to a table sorting clerk, then to a messenger, who again puts it in a pneumatic tube to one of the telegraph galleries (operating halls). Again in the gallery it goes through the hands of a sorting clerk, and then a distributor takes it to the circuit box, where it is dealt with by the traffic clerk of the circuit. An operator then telegraphs it over the line to Birmingham, where it is received by another telegraph operator. It is taken away by a collector to a delivery officer to be enveloped and addressed. Then finally a messenger takes it to the addressee. In the case of messages passing from city A through city B to city C the human chain is still further extended, but taking the foregoing as a fair average journey for a telegram, we see that between the sender and receiver of the message there are no less than 15 middlemen. In the case of long-distance messages this chain of middlemen may easily extend to 20 or 30. Not only is there heavy labour cost, but also much time is lost in this elaborate process. The result is that not only does an average telegram take an hour or more to reach its destination, but the excessive labour employed in handling it makes it very costly. Instead of 2d. for about 400 words, a telegram costs 6d. for 12 words—that is to say, 1d. for 2 words instead of 1d. for 200 as in the case of the telephone.

The vital importance of printing telegraphs lies in the fact that they can greatly reduce the present waste of line and labour in telegraphy, and that they render it possible to foster the growing co-operation between the telegraph and the telephone. The telegraph and telephone are each strong where the other is weak. We can set out the points in tabular form thus :—

	Telegraph.	Telephone.	Telegraph-telephone.
Time	Wasteful	Extremely economical...	Fairly economical.
Labour	Wasteful	Extremely economical...	Fairly economical.
Line	Very economical...	Very wasteful	Very economical.
Office equipment ...	Cheap	Expensive	Expensive.

If we utilise the telephone as the short-line feeder and distributor for the long-line telegraph we get the ideal co-operation shown in the last column of the table. The cost of office equipment will be increased, but this will be outweighed ten or twenty fold by the economies of line, labour, and time.

If telegraph messages were charged for like telephone messages, by

time instead of by the number of words, a lot of the labour cost would fall away. A merchant would then ring up the nearest telegraph office. He would be switched on to the required circuit, and he would dictate his message direct to a telegraph operator, who would type it on a rapid keyboard tape perforator. The perforated message would run through an automatic transmitter, and would be printed automatically direct from the line signals at the distant station, from which point it would be telephoned at once to the addressee. In this way the elaborate telegraph labour chain would be reduced from 12 or 15 to about 4, with corresponding reduction in the cost and saving of time. This may be an impossible ideal, but there is no reason why there should not be some approximation to it. Indeed, this telephone-telegram idea is already slowly emerging into everyday use. The British and other administrations now accept and deliver telegrams by telephone, and the British Post Office has actually coined the special name of "phonograms" for such telephone-telegrams. As telegrams can already be sent to or from a telegraph office by telephone, it is only a question of time for several more links in the long telegraph labour chain to be cut out, and *messages will be sent by telephone direct to the particular telegraph circuit over which they are to be transmitted.* There will be no more difficulty about that than there is in handling trunk telephone calls. It will be noticed, however, that the success of such an arrangement is conditional upon the rapid handling and transmission of the messages. If a merchant wished to dictate a message over the telephone direct to a telegraph operator on a particular circuit, and if he had not only to wait his turn, but also to dictate at the crawling manual speed of the Morse key and the operator writing at the other end of the telegraph line, the arrangement would never come into popular favour. The message should be recorded as perforated paper tape from dictation over the telephone at a speed of at least 60 words a minute, or it should be recorded at this speed or more on a typewriter at the circuit over which it is to be transmitted. Also the best the slow Morse key can do is to give two simultaneous transmissions in one direction on one telegraph wire. To handle "phonograms" under ideal conditions there should be a system giving either high automatic speed of transmission or at least four simultaneous transmissions in each direction on busy lines, and the speed of each transmission should be a steady average of at least 40 words a minute.

Not only would quick handling and transmission of messages be necessary, but also quick reception and printing of the messages at the other end of the line ready for transmission by telephone. Printing telegraphs are a necessity for such methods of handling telegrams. Even in the case of the general public, who would continue to hand in their telegrams in the usual way at telegraph offices, much time and labour would be saved if the messages could be sent by telephone from the local telegraph office direct to the trunk telegraph line and recorded on a keyboard perforator in the form of perforated paper tape, ready

for automatic transmission. The chief stumbling-block at present in the way of this arrangement is the practice of charging for telegrams according to the number of words. An incredible amount of time and labour is wasted in counting the number of words in telegrams. The telephone prospers without counting and recounting words. The telephone does not reckon "three-halfpence" as one word and "three hundred" as two words, to say nothing of other telegraphic word-counting absurdities. A rational system of charging for telegrams is badly needed, but it is difficult to imagine what plan could be substituted for the present clumsy but practical arrangement.

In addition to the telephone as a local collector and distributor of telegrams, there appears to be a field for the small step-by-step printing telegraphs generally known as stock-tickers. The Siemens and Halske teletyper is a good example of this class of machine. From a technical point of view it is an admirable little instrument, and on the Continent of Europe it is being exploited commercially with considerable vigour and success. It is quite largely in use in Germany, Berlin and several other leading German cities having ticker exchanges in connection with the head telegraph offices arranged somewhat on the lines of a telephone exchange. Any subscriber can send telegrams to the head telegraph office or receive them by means of the teletyper. By having one or two of these little instruments at each important circuit, and by having suitable switching arrangements in the exchange, subscribers could send in their messages direct to any required circuit or receive them direct from any circuit in the same way. The advantage of this arrangement would be that there would be a printed record of the message in the office of the sender and also in the head telegraph office, and it is probable that there would be less liability to mistakes than in the case of the telephone. These little machines, however, are more expensive and complicated and slower than telephones, and in the nature of things can only come into very limited competition with the telephone. The same remarks apply to the telewriter. This will also, no doubt, prove useful in collecting and distributing telegrams locally, but it is the telephone that will in time do the bulk of the local collection and distribution of messages sent over telegraph lines.

Meanwhile we have to see what steps we can take to reduce labour cost of telegrams under present conditions. The line cost also is important, but nothing like so important as in the case of the telephone, and, except in the case of very long lines, it is not so important as the labour cost. On the other hand, we have the letter post, by which we may send 5,000 or more words for one penny. The time of transmission is a good deal greater than in telegraphing over long distances, but there the advantage of the telegraph ends. Why spend sixpence on a telegram when you can telephone for twopence or send a letter for a penny or a postcard for a halfpenny? The answer is, that you cannot telephone for twopence except over short distances, and that letters take a long time to go long distances and telegrams do not. The telegram is the cheapest quick method of communication over con-

siderable distances. The subject is very complicated and there are many obstacles, but threepenny telegrams and quick service would lead to a wonderful growth of telegraph traffic. Threepenny telegrams and quick service depend on rational co-operation between the telegraph and telephone, upon the extension of the telephone to practically every office and home, and last, but not least, upon efficient printing telegraphs. It is a more or less instinctive appreciation of these facts that has led the British and other telegraph administrations to experiment so extensively during the past few years with various new printing telegraph systems. Much yet remains to be done, but it is practically certain that in the course of the next 10 or 15 years the British Post Office alone, to say nothing of other administrations, will have to spend not less than a quarter of a million sterling on printing and other telegraph machinery in telegraph offices—that is to say, on "office equipment." There are, of course, many other relative advantages and disadvantages of the telephone, telegraph, and letter post, but it is not necessary to discuss them here, as they have no special bearing on printing telegraphs.

PART II.

Difficulties in General.

The printing telegraph inventor has to dance in chains, which are none the less heavy because they are invisible. He has to conform to most intricate and unexpected conditions, and although the telegraph administrations are benevolently disposed, and do all they can, in the public interest, to assist in the development of printing telegraphy, they are still bound to look at the matter from the financial point of view, and to insist on a printing telegraph showing either (1) a saving of labour, or (2) a saving of line, or (3) a saving of time in transmission, or if possible all three. In fact, we may say that the difficulties in the way of introducing printing telegraphs are essentially commercial. The employment of printing telegraphs involves a considerable increase in the cost of office equipment, and there must be a substantial justification for that expenditure in the shape of saving in line, labour, or time. The most attractive feature in the eyes of the majority of telegraph administrations is the saving of labour, and the saving of labour by means of a printing telegraph is a peculiarly intricate problem. Time and labour saving in telegraphy are often antagonistic, and in this case we have to face one of the maximum problems, of which there are so many in our modern civilisation. We have to calculate and balance out the gains and losses of time and labour so as to get the maximum benefit.

As a practical illustration we may take the question of automatic tape transmission of signals *versus* direct transmission. This happens to be one of the most important of these maximum problems—these compromises between time, labour, and line saving. At the first glance

direct transmission seems to be the best, and most printing telegraph inventors have adopted this plan, but it is not the most economical, and it is not necessarily the quickest. Take the case first of direct transmission on a keyboard limited to, say, 40 words a minute. The operator's maximum speed is limited to 40 words a minute, and his average will certainly not be more than 30, apart from any stoppages to decipher badly written messages, to pick up and lay aside messages, and to sign and time them. All these delays on the part of the operator mean loss of time on the line and diminished carrying capacity for traffic, unless a second operator is assisting him so that he may send continuously. This plan, however, means waste of labour. On the other hand, with automatic perforated tape transmission on a transmitter running at 40 words a minute there are none of these delays. Transmission is continuous, and the operator working on a keyboard perforator finds no limit to his speed of operation. His short stoppages do not stop transmission, which is continuous. Actual trials on the Murray multiplex at 40 words a minute show that an operator can do double as much work with automatic tape transmission as with direct transmission. Not only is there 100 per cent. increase in the efficiency of the labour, but there is corresponding increase in the carrying capacity of the line. Also, although it may be said that there is a minute or so extra delay in perforating a message before transmission, and that therefore direct transmission saves time, this is not the case if there is pressure of traffic, because automatic tape transmission, by increasing the efficiency of the operator and the carrying capacity of the line, clears off traffic more quickly and reduces any tendency for messages to accumulate.

The only alternative in the case of direct transmission keyboards is to speed up the machinery from, say, 40 words a minute to, say, 80 words a minute. In this case the speed of the keyboard is above the maximum speed of the average operator, and it is practically free, like a typewriter keyboard. In this case, therefore, the operator can deal with as much work as on a keyboard perforator for automatic tape transmission, but this advantage is only obtained by a great sacrifice of line-carrying capacity. One operator cannot average by the hour more than about 30 words a minute, so that the line is used at 80-word speed for a 30-word output. With automatic tape the 80-word speed would give two simultaneous transmissions of 40 words a minute each, and the carrying capacity of the line would be doubled. On circuits where the traffic is not heavy, and where the carrying capacity of the line is much above requirements, the speeding up of the direct transmitter is a practical plan, and will come into use on such lines, but not on lines where there is heavy traffic.

One of the fundamental features of telegraphy is that a very large proportion of the total work must be performed by the human hand and mind. It can never reach the condition of a modern flourmill, where grain goes in at one end and flour comes out at the other with a minimum of labour. Telegraph messages cannot be made to flow

along automatically in a steady stream under the watchful eye of a few supervisors. On the other hand, suitable printing telegraph machinery and the assistance of the telephone can greatly reduce the amount of labour at present required for handling telegrams. In small countries with dense populations like England, France, and Germany, time and labour saving are the most important points. In Europe the distances within each country are, in most cases, comparatively short, and the differences of language reduce the number of long-distance messages to a small fraction compared, for instance, with the long-distance traffic in the United States, especially when it is remembered that the United States has only a population of 90 millions and Europe has over 300 millions. If Europe was a united one-language country the long-distance telegraph traffic would be enormous, and the printing telegraph problem in Europe would take on a very different aspect from what it has at present. Many difficulties that are now almost insurmountable would disappear. On the other hand, the telegraph traffic within each European State over comparatively short distances is often very heavy. Conditions in Europe are, therefore, different from the conditions in the large new countries. In Europe, excluding Russia, labour saving is most important, especially as the telephone has cut into telegraph traffic to such an extent that during the past few years the growth of telegraph traffic in most European countries has been small or nil. In Great Britain underground cables have increased the superfluity of telegraph wires for the time being. Hence Western European administrations have enough telegraph lines in most cases, and means of increasing the carrying capacity of the lines are not urgently required. On the other hand, the cost of maintenance of lines and the number of wires on poles are serious considerations that weigh in favour of line saving.

In the giant new countries with magnificent distances, including the United States of America, Russia, Canada, South Africa, the Argentine, Brazil, and Australia, the saving of wire is of the greatest importance, and some waste of labour may be tolerated if there is compensating line saving. Here again we have a maximum problem. The relative advantages of line and labour saving have to be balanced to get the maximum benefit.

The foregoing considerations make it easy to understand that the amount of labour that must be performed by the human being, the head-work that cannot be done by a machine, in connection with commercial telegrams is always large, and in the nature of the case there can never be results in labour saving like those in industries where the great bulk of the work is of a simple routine character easily performed by machinery.

The Labour-saving Problem.

The difficulties in the way of labour saving in telegraphy may be roughly classed under two heads: those in connection with commercial

messages, and those in connection with press messages. Dealing first with commercial messages, these are short and average about 20 words. Continual stoppages of the mechanism every 20 words are therefore necessary. There is no continuous run, and automatic factory production is not possible. At first sight saving of labour on commercial messages might appear to be easy, but investigation will show that it must of necessity be small. It is impossible to have a machine that will enable one man to do the work of 15 or 20 men, a thing by no means uncommon in the industrial world. A printing telegraph that would merely reduce the amount of labour by half would be a very fine system indeed, and it would effect very nearly the maximum possible labour saving. Take a printing telegraph that can run at 150 words a minute. If it could keep running continuously it would be able to turn out 400 messages an hour. But it has to stop every 20 words or less, and then there are corrections and repetitions and inquiries, also stoppages of the apparatus, breakdowns, line interruptions, pauses for adjustment, and irregular flow of telegraph traffic. All these causes lead to a sad reduction in the output and disappointment to the printing telegraph inventor. If screws never came loose, and metal never broke, and steel never wore out, and human beings never made mistakes, and if telegrams always came flowing in at the uniform rate of four a minute, printing telegraph systems would perform miracles of labour-saving, but they do not. With tape printing the tape has to be cut up and pasted on message forms and the messages signed and timed, the number of words counted and checked, and a note made of the preamble and address. With a page-printing telegraph the loss of time in cutting up tape and pasting it on message forms is saved, but provision has to be made and time allowed for line-feed, column-feed, and page-feed. These delays take place every 20 words or oftener, thereby considerably reducing the saving possible in theory.

The position is entirely different in the case of the stock-ticker and ticker news service. As in the case of the telephone and the telautograph, transmission in the case of the ticker is direct and there are no middlemen. There is no counting of the number of words in messages, no checking the messages, no questions asked from the receiving stations, no envelopes to be addressed, no registered addresses to be looked up, and no delivery of messages. In the case of the ticker practically the whole of the troubles are questions of mechanical maintenance.

Press Messages.

Turning now to press despatches, the conditions at the first glance are much more favourable for printing telegraphy, but actual experience shows that the obstacles are much worse than in the case of commercial messages. It is true that press messages are long and therefore very favourable for machine telegraphy and for labour

saving. The Murray automatic printer, for instance, can print news despatches easily at the rate of 200 words a minute. That is to say, it enables one man to do the work of six operators writing out messages from Wheatstone tape by pencil or typewriter. The service conditions, however, are so intricate that it is difficult to see how a printing telegraph could do anything more than a fraction of the work, at present at any rate.

The British system of news distribution is divided into the Post Office "News Division" worked by the Wheatstone system, and the leased and private wires rented from the Post Office by the leading British newspapers. London is the great originating and distributing centre for news, and it flows out from London all over the United Kingdom. The amount of news that comes up to London from the provinces is comparatively small. Taking first the Government service, in the British "News Division," news distribution is carried on by an elaborate arrangement of Wheatstone circuits, each message being perforated simultaneously on from one to eight tapes by pneumatic perforators, the tapes being then used to transmit press messages over as many as 30 different Wheatstone news wires, many of which have four or more towns strung on them in series. In this way news is distributed all over the United Kingdom at a very rapid rate, and with remarkable economy of labour, as one man can prepare a message for transmission to a hundred or more towns. There are very great difficulties in the way of any printing telegraph coming in and doing this work. In the first place, the news is distributed at a very high speed of from 200 to 300 words per minute. No printing telegraph can work steadily at such a speed on one wire. Also the Murray automatic system, and indeed any other printing telegraph using a special alphabet (not Morse), would require a piece of news to be punched in the Murray alphabet as well as in the Morse, unless the whole news service of Great Britain was handled entirely by the Murray automatic system. Apart from the speed difficulty and the cost of the apparatus, it would take years for a printing telegraph to be installed all over the country. Using it for a few circuits for news would mean double labour in perforating the message in two kinds of tape, one for the Murray and one for the Wheatstone. Other advantages might be great enough to compensate for this extra labour, but the speed of the line would have to be dropped to about 150 words a minute. It was for these reasons that the Murray automatic system was not tried on news work by the British Post Office when it was first brought over to London from New York in 1901. At that time also its speed was only 100 to 120 words a minute. The line speed has now been raised to a maximum of 184 words (1,104 letters) a minute and 200 words a minute for printing, but this is still insufficient for news requirements in Great Britain. Instead of news work it was put on to commercial work between London and Edinburgh. On that work quite different difficulties were met with. These will be dealt with presently.

A printing telegraph using the Morse alphabet would be more easily employed in the British "News Division," because it would fit in as part of the present news service. With this idea an inventor named Creed applied a differential feed to the Murray automatic printer so as to enable it to print messages from the ordinary Wheatstone Morse perforated tape. He also designed a very ingenious and useful receiving perforator to reproduce Wheatstone tape at the receiving station at a speed of about 150 words a minute. This worked quite well, for a time, but owing to its extreme complexity and its high cost, the Post Office only used the Murray-Creed printer to a limited extent. The British Post Office has plenty of wires at night available for transmission of news messages, so that a comparatively low speed, such as 150 words a minute, is not an absolute bar to the use of a printing telegraph; but it is not economical to have too many wires in use, because each wire requires a receiving clerk in constant attendance at each office. For instance, on the Scottish news, if an extra wire is opened a clerk is required in London, Newcastle, Edinburgh, Glasgow, Dundee, and Aberdeen—that is to say, six additional operators for one additional wire. This extra labour would be a considerable offset against any labour saving by a printing telegraph. It is possible that in time the Murray automatic system may come into use for news work. That is the purpose for which it was originally designed; but the prospects are not bright.

In other countries where there is no highly complicated arrangement for news-distribution, there is no obstacle to the use of such printing telegraphs as the Murray automatic; but in countries where there is no complicated news-distributing organisation there is very little news traffic, and it can be handled easily by the Hughes and other low-speed and therefore cheap instruments. The field for news distribution by rapid printing telegraphs is not large outside of English-speaking countries, and inventors have therefore confined themselves chiefly to the more important field of ordinary commercial telegrams.

Another difficulty about news work is that in London and other large centres of population at least 12 copies are required of press messages for various newspapers. It puts a serious strain on any typewriter to make 12 copies continuously for long periods of time at a high speed. Rotary mimeographs and hectographs get over the difficulty in New York, and there is no reason why they should not do equally well in London.

As an illustration of the perfection of British news distribution, it may be mentioned that the British Post Office has successfully transmitted news at the rate of from 250 to 300 words a minute on a Wheatstone circuit from London, feeding Newcastle, Edinburgh, Glasgow, Dundee, and Aberdeen. In cases where a series of towns are strung on one wire in this way all the messages are sent through and each town picks out what it wants without asking any questions or interrupting the flow of news on the wire. In cases like this,

and there are dozens of such circuits in the British News Division, a printing telegraph is at a grave disadvantage. A system worked in this way must not break down, and the high-speed printing telegraph that will not break down occasionally has not yet been invented. If one of the stations breaks down, the messages lost to that station must be repeated to all the five or more stations of the circuit. This involves delay and waste of labour, as each station will have four or five men, or even more, in attendance. Large stations will have 20 or more to write up the messages from the Wheatstone tape.

Newspaper Private Wires.

In the case of the private wires rented from the Post Office by British newspapers, the conditions that exist are even worse from a printing telegraph point of view. High-speed printing telegraphs are of necessity complicated and require good mechanical skill to keep them in order. All telegraph offices of any importance have several skilled mechanics to keep the telegraph apparatus in order, but newspapers have none. They have skilled engineers accustomed to large machinery, but small and complicated instruments are quite out of their line. That fact in itself is a most serious difficulty. It means that a skilled mechanic with an assistant and a small workshop would have to be installed. The question of speed also is just as serious with newspapers as with the Post Office. Take, for instance, a great provincial daily paper like the *Glasgow Herald*. Every night it sends from 30,000 to 40,000 words (about 30 columns) from its London office in Fleet Street to its Glasgow Office 400 miles away. The great bulk of this extraordinary mass of news is sent over the *Glasgow Herald* private wire between 5 p.m. and midnight, and the conditions are such that it is absolutely imperative to have a speed of transmission over the line of not less than 250 words a minute (1,500 letters a minute) and preferably 300, especially as the night advances and the time approaches for going to press. Even with such high speeds it is occasionally necessary for the *Glasgow Herald* to send some of its news over the Post Office wires. At present the work is done by the Wheatstone system, and there is a staff of 6 to 8 operators in London, who punch the news in the form of perforated tape, and it runs through the Wheatstone transmitter at 200 to 300 words a minute, coming out in the Glasgow office of the *Herald* as dots and dashes on a tape, which is then copied out by a staff of 8 to 10 men. It is not apparent how any printing telegraph can meet such requirements as those of the *Glasgow Herald*. The writer tried it with the Murray automatic system, but the utmost that he could achieve was 184 words a minute, and even this was with very fine adjustment, much too fine for practical work; 150 words a minute was practical, but it was too slow. Also the *Glasgow Herald* lays itself out especially for giving commercial news, and sends through from London every night several

columns of stock and market reports. These are full of intricate figures, and a special system is adopted. There are printed sheets in the London and Glasgow offices of the *Herald* containing all the stocks and shares ordinarily quoted on the Stock Exchange. A letter of the alphabet is used for each stock or share, and they are arranged into groups distinguished by the names of colours, thus: Red *a*, *b*, *c*, etc.; blue *a*, *b*, *c*, etc.; and they are telegraphed thus: Red *a* 2 5/16 7/16, *c* 1 15/16, *d* 3¼, etc.; green *a* 110–12, *b* 13 1/4, *c* 8 19/32, etc. Several columns of this have to be sent through without correction or revision of any kind, and there must be no mistakes. Under the present system mistakes are few. These prices are dropped into their proper places on the printed sheets in Glasgow by the operators who transcribe the Wheatstone tape. A printing telegraph that can do such work at 250 words a minute will take a lot of inventing. Less serious troubles are to be found in the fact that mistakes show up badly in the typewritten pages produced by printing telegraphs and make the sub-editors uneasy about the accuracy of the messages. In the case of the Wheatstone the transcribers correct the errors as they proceed, and they write out clean "copy." The sub-editors, seeing no mistakes, remain in happy ignorance of the frailty of telegraph lines and of human operators, and the editorial mind is at ease. News messages are also telegraphed with many contracted words. This saves time, but the contractions look bad in a typewritten message. When written or typewritten by hand, the contracted words are written out in full. Here is an actual example of a *Herald* message as it came through and was printed on the Murray automatic:—

"SIR W ROBSON SD T GOVT CD NT ACCEPT T AMDT WH WD STRIKE AT T ROOT O T DUTY."

"MR LLOYD GEORGE SD TT TO AVOID ANY AMBIGUITY HE WD MOVE AN AMDT WH WD MEET T POINT RAISED BY MR HILL."

The difficulties met with in connection with the *Glasgow Herald* private wire apply also in the case of other great British newspapers, such, for instance, as the *Daily Mail*, Manchester and Paris editions. These newspapers are all anxious to get some printing telegraph that will meet their requirements, but they are still waiting.

In spite of the great difficulties in the way of using printing telegraphs for news work it would be taking too pessimistic a view to say that printing telegraphs cannot be used for press despatches. They can be and they are so used. In Germany and France, for instance, where the newspaper telegraph traffic is small, all the press messages are sent over the Hughes and Baudot printing telegraphs, and even in Great Britain printing telegraphs will in time make their way for news work; but it will be a very slow progress and very costly. The apparatus will have to be faultlessly made and well-trained men employed to run it. There will probably be a saving of time, but the saving of labour will not be great.

THE "TOP COPY" DIFFICULTY.

It is the usual practice of telegraph administrations to keep a record of each message sent out for delivery. In some cases a note is made of the preamble and address. In other cases a copy of the whole message is retained. The custom of the British Post Office is to make a carbon copy of each message that is to be sent out for delivery, the original, or "top copy," being kept by the Post Office for reference and the carbon copy being issued to the public. When messages are written out by hand from the Morse sounder or from Wheatstone tape the making of a carbon copy of each message is a simple matter. The great bulk of British telegrams are dealt with in this way, but the gradual introduction of typewriters and printing telegraphs is rendering a change necessary, because it is not practicable to make carbon copies of messages when a typewriter or printing telegraph is employed. The reasons are as follows: In all countries there are two classes of commercial messages. In Great Britain these are known as S and X messages. The S messages are those for delivery to the addressees. X messages are those passing through town B from town A to town C. They are messages written down for retransmission over another circuit. These are not issued to the public and do not need to be copied. As much as half the traffic in large towns may consist of X messages.

In America wet press copies are taken of messages that go out to the public, and this method was proposed in London when the Murray automatic system was first started, in 1902, between London and Edinburgh, but various objections were raised to it. The Murray automatic printer could prepare from 12 to 16 good carbon copies of messages, but the carbon copy method could not be used because it was not possible to tell whether an S or an X message was coming over the wire at a high speed, and there was not time to slip in carbon paper for one message and not for another. Either all the messages would have to be carbon copied from a continuous roll or none at all. Arranging for carbon copies from a continuous roll was found to be very troublesome, expensive and impracticable. A variety of proposals were made. One was to have the platen of the typewriter itself covered with a jacket of typewriter ribbon material and a roll of tissue paper feeding in. The message would then print on the ordinary forms and give a tissue copy inked from the back by the ribbon cover of the platen. Investigation showed that this idea was not a good one. Another proposal was to blacken with the carbon composition the backs of the message forms, and they would then themselves supply a fine carbon copy on paper behind them. What the public would have thought of telegraph messages smudged all over the back with dirty carbon pigment is easily imagined. That idea was abandoned. The whole of the possibilities were gone through most carefully, and finally it was decided that the best way was to arrange for a "check-table" girl to make a written note of the preamble and address of all

S messages that came over the Murray circuit. As this work only occupied half the time of this operator, it was reckoned as the time of half an operator. Laboriously copying by hand at 15 words a minute with risk of error messages printed by a machine automatically at 100 or more words a minute does not seem very sensible, but it was the best thing that could be done under the circumstances, and it has been adhered to until quite recently. On the Hughes circuits also a check girl notes for record the preamble and address of Hughes messages. One reason for this arrangement is a good illustration of the complexity of telegraph work. The girl at the check-table was advantageously employed for this work because she was a "circulation expert," and, therefore, only copied S messages, her experience enabling her to tell at once which were S and which were X messages. For instance, "Silvergray, London," has to be delivered at Silvertown. It is therefore an X message and need not be copied in London. For part of Oxford Street, London, messages are delivered by tube, and part needs a telegraphic retransmission. Operators do not know the tube deliveries, but the circulation experts do. Of course, the whole of this trouble would disappear if the messages were press copied in the delivery office, where there are no X messages. Another proposal was that as the Murray automatic printer printed the messages from a perforated tape, any S messages should be printed twice by pulling back the tape and reprinting from it. This was tried and found to waste too much time. The only practicable method, therefore, is wet-press copying as done in America. There, a roller copier is used driven by a small motor. This was tried in London, but various difficulties were met with. Damping the sheets of tissue and handling the damp tissues proved anything but successful in the rush of telegraphic work. At that time the elaborate roller press copiers now in commercial use had not been developed. A photographic roller enameller was tried and with a few alterations gave good results. Bunches of tissue paper were soaked in water, and then run through the rolls to press out superfluous water, but the sheets were found to be so difficult to separate that much time was lost and the arrangement was impracticable. Also the damp tissue had a tendency to stick and wrap itself round the rollers of the copier. An American telegraph operator, who happened to be in London at the time, showed how it was done in America. Blowing sharply with the mouth on the edge of the mass of damp tissues separated them at the corners instantly, and enabled them to be pulled apart quickly. He also showed that 8 or 10 telegrams could be copied simultaneously by piling them up interleaved with the damp tissue sheets, folding the bundle in half, and running it through the rollers. The folding prevents the tissues sticking to the rollers and halves the time required to run through. In America, where the use of typewriters for telegraphic work is universal, the wet-press copying of S messages is done in the delivery office. This is simple and convenient; but when a new printing telegraph is being introduced in a country where messages are received by Morse

sounder and written out with pencil and carbon paper, it is obvious that a press copying outfit cannot be installed in the delivery office for the sake of a few hundred telegrams a day, out of many thousands. That would waste much time and labour. Copying must be done near the receiving mechanism of the circuit until typewriting or printing telegraphy comes into fairly general use in the large towns. Also the copy must go with the message to the delivery office. It could not, therefore, be taken on a press copier using a continuous roll of tissue paper. The damp-press copies would also have had to go with the messages rolled up in bundles, through the pneumatic tubes, and that would have been liable to cause trouble. To avoid this difficulty it was proposed to use alcohol instead of water to damp the tissue paper, paper so damped giving an excellent copy from methyl-violet type-writing ink, and the alcohol dries quickly. The danger of fire, however, prohibited this idea. Under all the circumstances, copying the preamble and address by hand was the only thing possible. Recently the development of the modern press copier for commercial office use has brought the question up again. Rolls of tissue paper already damped with glycerine and water are obtainable, and these retain their slight dampness for a considerable time as the glycerine is hygroscopic. But these big press copying machines are useless in cases where the copying has to be done at the circuit. The cost of the copier for a single circuit, the space occupied, the labour, and the delay in cutting up tissue into separate messages to accompany the originals make it useless. In the delivery department one of these modern press copiers is very suitable, as all messages there are S messages and have to be copied, and one copier can handle the messages from many circuits. In America, before the introduction of the typewriter for telegraph work, the pencil and carbon paper method still used in Great Britain was employed. With the Morse key and sounder and hand-written messages this plan is ideal, because the operator has ample time to slip in a sheet of carbon paper when necessary. With the introduction of the typewriter there was no longer time to slip in carbon paper for some messages and not for others, and there was too much waste in copying all messages in this way when only about half needed copying. The Americans being more enterprising and less embarrassed by imaginary obstacles, wet-press copying in the delivery office was established as a matter of course.

In England another serious obstacle to the introduction of a rational method of copying telegrams was as follows: Some progressive officials in London, greatly daring, urged that the "top copy" should be done away with. They said, "Abolish it. We have the message as handed in by the sender, and if the recipient has any complaint to make let him produce the received message. We can then compare the two copies and see what is wrong, and refund the 6d. for the telegram if the Department is to blame." The abolitionists, however, have not been able to overcome the scruples of the Auditor-General of

the Post Office, who for financial reasons has an elaborate system of checking the telegrams and the number of words paid for. The subject is really excessively complicated, and it has been dealt with fully here because it is a good illustration of the difficulties that the printing telegraph inventor has to face, subtle, invisible difficulties that even highly trained technical telegraph men do not themselves realise till they come up against them. Wet-press copying in the delivery office is rapid and free from error, and it is the only practical method of copying messages when printing telegraphs are used and when only some (roughly about half) have to be copied; and in time it will be adopted in all cases where a telegraph administration finds it necessary to preserve a copy of messages sent out.

S and X Message Forms.

The distinction between S and X messages has already been explained. X messages are well named because they cross through city B from city A to city C. An X message in city B becomes an S message in city C, where it is to be delivered. Not only do these two different kinds of messages give trouble in connection with making copies, but they also give rise to a further obstacle so far as page-printing telegraphs are concerned. Practically all administrations have two kinds of telegraph forms or blanks for the two kinds of messages. In the case of printing telegraphs like the Hughes and Baudot, which print their messages on a tape, the S and X message forms present no difficulty as the tape can be pasted on to either as may be required, and in any position. For instance, in France the piece of tape containing the address is pasted on the back of the message form, and in Germany in the middle at the top. Also in the case of the Morse key and sounder, it is an easy matter for the operator to select an S or X form as may be required. In the case of a page-printing telegraph, however, it is impossible to know whether an S or an X message is coming over the line until the printing of the message starts, and then it is too late to change the form, and it would cause too much waste of labour if the sending station had to announce beforehand whether an S or an X message was being sent. The only way out of the difficulty in the case of a page-printing telegraph is to have one kind of form for both S and X messages. Administrations are reluctant to make changes like this in their established forms. In Great Britain also there are two different forms for inland and foreign telegrams, C forms in the case of foreign and B forms in the case of inland messages. The same difficulty arises here also, and one form has to be used for both. Those who are sufficiently interested in the matter will find at the left-hand top corner of page-printed telegrams that they may receive in Great Britain the letters C or B, meaning that the form is to be used for either inland or foreign telegrams. When the Murray automatic page-printing telegraph was brought from New York to London in 1901, the British Post Office had to prepare a special telegraph form for it combining the S and X and

the C and B forms, and to make it distinctive the heading was printed in green ink. A special form had to be adopted for it in Germany and other countries also for the same reason. Fortunately the advantages of page-printing are more than sufficient to counterbalance this initial inconvenience.

NUMBERING MESSAGES.

There are other difficulties that are confined to one Administration. For instance, in America and on the Continent of Europe it is customary to number each message consecutively. The receiving operator can then tick off the messages on the number sheet as he receives them. A missing message is noticed at once. The British Post Office used to employ numbers for messages, but eventually abolished numbering as it was found not to be absolutely necessary with the Morse key and sounder. Numbering was also abolished in the case of the Wheatstone. Instead, the "name to" of messages was written on slips kept for the purpose. This seemed unnecessary, and the messages were then run in batches of no definite number, and the "received" signal to the distant office was "R D batch" (received batch) at the conclusion. This rather loose practice has now been modified, and a record is again kept of each name and acknowledgments are sent in bulk. This means waste of time, but the numbering wastes line time, which is worse, especially when the line is in bad condition and there is no speed margin. Numbering messages involves a waste of about 2½ per cent. in line-time and labour, and as every signal costs money in telegraphy the tendency is to omit all unnecessary signals. Whether consecutive numbers on telegrams are necessary appears to be an open question. Certainly numbering is a safeguard against messages being lost—an accident that happens occasionally in all telegraph offices. Hence when the Murray automatic system was introduced into the British telegraph service it was considered desirable by the officials to resume the numbering of messages on the Murray circuit. This is a small matter, but it involved a certain amount of change of routine, and in a big department a change of routine is a matter of difficulty. It certainly is to the credit of the British and other telegraph Administrations that they have shown such willingness to make these and other considerable changes to accommodate the Murray and other printing telegraphs. The experience of the writer is that the real conservatives are not the official heads but the operators, who often show extraordinary reluctance to accept change of routine. In fact, that is one of the minor obstacles to the introduction of printing telegraphs. Of necessity, in the case of a new machine of this kind, improvements suggest themselves after months of practical experience; but by that time the operators have become accustomed to working the machine, and over and over again the writer has been told that improvements he had made were changes for the worse and that "the old machine was much better." It takes weeks before an improvement gives satisfaction to all.

Counting Words in Telegrams.

Following upon the numbering of telegrams comes the numbering of words in telegrams. This is a serious matter causing much waste of time and labour. It is a burden from which the telephone is free because the telephone charges by time and not by the number of words. Charging by the number of words is a very defective system, but it is difficult to say what better arrangement could be adopted. As long as word-counting remains in force it will be one of the hindrances to any considerable saving of labour by printing telegraphy. The number of words in the message is sent in the preamble, and it is the duty of the receiving operator to count the number of words in the received message to see that it agrees with the number in the preamble. If it does not it is a case of "wrong number." Suppose the preamble gives 14 words and the receiving operator can only count 13. He telegraphs back the recognised British inquiry signal "R Q" and adds "13 *w*." The operator at the sending station then repeats the first letter of each word in the message until the missing or superfluous word is found. This is a specially easy and quick process with the Morse key and sounder, but it is not so quick with any printing telegraph because talking back and forward is not so quick as with the Morse key. Counting the number of words in a message is a valuable check on the accuracy of transmission. Also the administration is bound to transmit the number of words that have been paid for; but the waste of time and labour on counting words is quite considerable. In telegraphy "wrong number" is one of the most frequent "R Qs," and, in fact, when the apparatus and line are working well there is hardly any other. Often 60 or more messages will go through without a single correction or inquiry except on account of "wrong number." Probably in more than half of these cases the message has been correctly transmitted, but the number of words has been wrongly counted at the sending or at the receiving station, and an agreement has to be reached on this point before the message can be passed on. It seems an easy matter to count the number of words in a telegram, but in reality it is quite difficult and requires experience, and it makes the task of the receiving operator distinctly responsible. Not only may the sending and receiving operator count the number of words wrongly, but they may differ in their methods of counting. There are a very large number of words that may be described as more or less Siamese twins. You can call them one or two as you please. There are many official regulations on the subject. "Fishmerchant" is sometimes counted as one word and sometimes as two. The receiving operator has to ask sometimes how it has been counted. There are two Ashursts in England, and to distinguish the second one it is known as "Ashurst Hants," and this counts as one word equally with "Ashurst." There are hundreds of similar cases all over the world. Also there are many new Siamese twin words born almost every day, and lists of words to be counted as one or as two are issued from time to time. "Motor spirit" is counted

as one word. The German word "Sagomehl" (sagomeal) is reckoned as one word in Germany but as two words in England. "OHMS," the contraction for "On His Majesty's Service," is counted as four words if in capital letters; but when printed in small letters, thus "ohms," it is the unit of electrical resistance and is one word. Printing telegraphs, however, usually employ capital letters and figures only. The words would then go in capital letters OHMS. On the other hand, in Germany small letters and figures only are used in telegrams, and the contraction for "On His Majesty's Service" would then appear as "ohms." This is not the only puzzle in counting words. According to the regulations of the British Post Office—

"Already" is one word,
"Alright" is two words.

"Errands" is one word,
"Erands" (contraction for East Rands) is two words.

"Blackbird" is one word,
"Whitebird" is two words.

"Three half pence" is one word,
"Three hundred" is two words.

"Motorbus" is one word,
"Motordriver" is two words.

"Motorboat" is one word,
"Motorlaunch" is two words.

"STCATHERINESONTARIO" is one word,
"PRESSASSN" is two words.

It is only fair to say that similar anomalies are to be found in the case of all telegraph administrations. They certainly do not smooth the path of the printing telegraph inventor.

Errors in Telegrams.

Apart from these difficulties, the most serious trouble a printing telegraph system has to face is errors in telegrams. The sender of a telegram may make a mistake, or his handwriting may be bad. The operator who transmits a telegram may make a mistake. The sending apparatus may cause an error. Disturbances on the telegraph line, stray currents, inductive interference, men repairing the line, wind and weather, may all introduce errors into a telegram. The receiving apparatus may cause a mistake. The receiving operator may not notice the mistake and the message may go on for retransmission to another town. The retransmitting operator may make a mistake, and the chain of points where errors may occur are repeated with each retransmission. Considering the possibilities, it is remarkable how few errors actually occur in telegrams.

In an ordinary message nine errors out of ten in words are sufficiently obvious to induce the receiving operator to ask the transmitting station for confirmation or correction. With figures, on the other hand, the context is no guide, and a mistake in figures is not detectable by inspection. In cipher messages containing groups of figures, the code maker's practice of adding up each group of figures and telegraphing the total as a check can be followed. This plan has the advantage that the check signal is brief, but it does not guard against horizontal transposition of the figures unless the adding is done vertically. Assume, for instance, that the message contains the figures 23 371 27 17 6. Adding up these figures horizontally gives 39, which again gives 12, which finally gives 3. Obviously any transposition of these figures will make no difference in the total, and the error of transposition is very common. Addition guards against a wrong figure, but it does not guard against two wrong figures cancelling each other's error so as to give a correct total—7 and 3, for instance, instead of 6 and 4. The chances against this are large, but it is possible. Also it does not guard against a wrong figure and a wrong addition neutralising the wrong figure. The chance of this, however, is very small. Adding the figures vertically we get—

$$23 + 371 + 27 + 17 + 6 = 444.$$

Any horizontal transposition will show at once in this total. Further additions, however, will give the same total 3 as before. That is to say, three 4's are 12, and 1 and 2 are 3. The figures can be transposed in any possible way vertically or horizontally, and the total will always be three. As a check for a few figures addition is of little value, but for long cipher messages it is a useful though not infallible check.

Repeating the figures is a check always used in the British telegraph service with the Morse key and sounder, but this also is not a perfect check, because the human mind is so liable to fall into habits; and if an operator sends a wrong figure he is very liable to repeat his mistake when repeating the figures at the end of the message. Also if an operator receives wrongly the error is liable to go unnoticed in spite of repetition, especially 3 for 4 or 4 for 3 in Morse, these Morse figure signals, when repeated, differing only by a single dot, thus :—

3 - - - ——
4 - - - - ——

With keyboard sending there is the additional risk that some defect may develop in the instrument, causing a particular figure to miss occasionally, and repetition of the figure will be liable to repeat the error. The human failing is thus paralleled by the machine. This rarely happens with any of the good modern keyboard instruments for sending, but the possibility is there. A figure check that is practically perfect was suggested by Mr. W. A. Hatfield, a member of the British Post Office engineering staff. It consists in the repetition of figures

that occur in the address and text of the message as letters at the end of the message—thus: $a = 1$, $b = 2$, $c = 3$, etc. This is taken from the British telegraph clock code time, in which $a = 1$ o'clock, $b = 2$ o'clock, and so on. This code is well known to the British telegraph operators. Hence its use as a figure check in the British telegraph service is very easy. In any case it is not difficult to learn. It will be noticed that different keys are employed to repeat. This guards against an error due to a defect in one figure key being repeated, and it also prevents the operator repeating an error through habit. The arrangement was adopted with the Murray automatic system, the figures being repeated as letters in a separate line at the bottom of the message. This reduces the output of messages, probably by about 10 per cent., but it is an admirable safeguard, particularly in the early stages of a printing telegraph system before all the mechanical troubles have been overcome. When cipher messages consisting of groups of figures are being transmitted, the repetition of figures as letters is cumbersome, and transmission at the end of the message of the sum of each group of figures would probably be the best check. Up to the present the code makers are the only people who have availed themselves of this plan.

The great majority of the small errors made on keyboards are transpositions of letters, such as "aer" for "are." Some of these transpositions are rather puzzling. For instance, "Sne dat once" needs a moment's thought to see that it should read "Send at once." This was an actual mistake, and it is interesting because it is a case of double transposition. *E* and *n* are transposed and then the space and *d*. Double transpositions are not uncommon. When the mind stumbles it often stumbles again in trying to recover itself. Other errors of this kind that have actually occurred are "Engaldn" for "England" and "Motnsh" for "Months." Transposing is a common error also in writing. It is not confined to typewriting.

It is necessary for the operator to have considerable experience of telegraph messages to perceive mistakes. For instance, "fmcht" is clearly a mistake to any one not acquainted with the subject, but it happens to be the customary contraction for "fishmerchant." A good example of the care and discretion necessary in checking received telegrams is as follows. One day a telegram came through something like this, "Buy 100 tintos for ries." Apparently the sending operator had fallen into the usual error of transposing. He had mixed the *e* and the *s*, and the telegram should have read, "Buy 100 tintos for rise." Fortunately the receiving operator asked the sending operator whether "ries" was right, and it was. That telegram came through without error, but it involved delay and an inquiry. There are many such telegrams, and they materially reduce the number of messages that an operator can handle per hour, and thereby increase the cost of telegraphy to the general public. On the telephone there would have been no doubt about that message and no delay. If telegraphy was straight-ahead routine work in a steady, continuous stream all day, without any need for head-work on the part of the operator, telegrams would only

cost a quarter of what they do now, and the printing telegraph inventor would have an easy task.

Another fertile source of errors in telegrams is careless and indistinct handwriting on the part of the public. For example, cruisers certainly are bruisers, and the British Admiralty would like to be Almighty, but a certain editor must have been rather surprised when he got a telegram announcing that "The Almighty has ordered three new bruisers." In this case the operator was also to blame for allowing such nonsense to pass, but in the following instance the operator was not at fault, as the mistake probably arose from the use of the old-fashioned *s*, written very like *f*. A man in London told his wife in New York to come over to London by a certain steamer, and then at the last moment decided to go to New York himself and accordingly telegraphed to his wife, "Don't sail." The telegram as it reached his wife read, "Don't fail." She took it as instructions to sail without fail, and she did so, only to find on arriving in London that her husband had also sailed without fail to New York. Another class of errors is that due to defects in the apparatus. Printing telegraphs, especially new ones, drop letters occasionally. In one instance in London the letter *z* was missed from the address "Zurich," so that the message read "Urich." By some unhappy chance there is a town named Urich in Montana, in the United States, and the telegram accordingly went to America instead of Switzerland. The mistake was not discovered till the message had come back from Urich in America, undelivered, two days afterwards.

On the other hand, it is the general experience that good printing telegraphs reduce the number of errors in telegrams compared with the Morse key and sounder. Printing telegraphs eliminate a whole class of errors due to misreading of Morse signals. Also signals sent by a machine are of necessity more precise and accurate than hand signals can possibly be. It is for this reason, amongst others, that automatic transmission is now practically universal on ocean cables. It is an undoubted fact of experience, both in Great Britain, the United States, and other countries, that printing telegraphs, when in satisfactory working condition, reduce the percentage of errors very materially compared with the Morse key and sounder.

As an example of a Morse error the following may serve. A message was handed in at an office in Ireland: "Deliver ten pigs." This was mutilated in transmission into "Blister ten pigs." The Morse signals are identical, but the spacing differs, thus:—

```
   D    E    L         I         V      E     R
 ——— - -  -  - ——— - -  - -  - - - ———  -  - ——— -
   B         L         I    S    T  E     R
 ——— - - -  - ——— - -  - -  - - - ———  -  - ——— -
```

Complaint was made about the pork and mustard error, damages claimed, and sixpence, the cost of the telegram, was refunded by the Post Office.

Not only is long experience necessary for the quick detection of errors, but familiarity is also desirable with the traffic on particular circuits. Registered addresses are often peculiar, and slight mistakes on the part of the sending operator might cause a wrong delivery of a message. Experience on a circuit will detect such errors at once, as registered addresses occur frequently on particular circuits and become familiar to the receiving operator. Also the usual trade contractions must be known—for instance, "fmcht" for "fishmerchant." "Ystrádyfodwg" is a real name, though it does not look right to the uninitiated. "Gwrwch," another Welsh town, is also correct, although its looks are against it. "Gablonzanderneisse" is obviously correct, and "Stcatherinesontario" and "Stmaloilleetvilaine" are quite right and count as one word each. Printing telegraphs occasionally become what the French call "derailed" for a few seconds, and a meaningless jumble of letters is printed. Fortunately this kind of error is recognisable after a little experience, as the "derailment" gives characteristic results with each kind of printing telegraph. Hence the only evil consequence is a little delay. Code and cipher messages are also a sore trial for the telegraph operator, but such messages come through, on the whole, more accurately on a good printing telegraph than with the Morse key and sounder.

The method of getting corrections and making inquiries is ingenious and brief. R Q is the British signal for an inquiry, and the following contractions are used—

A A = All after.
W A = Word after.
L W = Last word.
M M = Office of origin.

"What is the word after urgent in message No. 125" would be sent "125 W A urgent." If the last word is in doubt, the inquiry would be "125 L W." The sending operator also anticipates inquiry in regard to curious words by repeating them at the end of the message. This saves time.

Variety and Irregularity of Telegraph Traffic.

A special difficulty for printing telegraphs is to be found in the variety and irregularity of telegraph traffic, which varies greatly in volume and in character according to the circuit and the seasons. In Great Britain, for instance, the telegrams from the Channel Islands are largely telegrams about early potatoes and other produce, and they are in many cases "multiple address" messages—sometimes two addresses, sometimes three, sometimes a dozen or twenty. Other circuits have heavy fish-traffic, such as Grimsby. Others, like London to Brighton, are largely social and domestic. There are great variations of traffic according to the seasons, and much more traffic in summer than in winter, at any rate in Great Britain. There are also

great variations in the volume and kind of traffic according to the hours of the day. British telegraph traffic divides itself quite distinctly thus :—

7 to 9 a.m.—Fish and meat telegrams (provision market work).
9 to 11 a.m.—Births and deaths and a little Stock Market.
11 a.m. to 1 p.m.—Stock Market and commercial messages.
1 to 4 p.m.—Racing, betting, and ordinary telegrams.
4 to 5 p.m.—Ordinary messages.
From 6 p.m. onwards, Press messages.

The work is quite distinctly divided in this way, and the telegraph operator can watch the habits of the people, when they get up, when they start work, and so on. The number of betting telegrams in Great Britain is very large, especially from Ireland. There will be a considerable loss of revenue to the British telegraph service when the law finally puts a stop to this betting vice. There are similar irregularities in the traffic between Great Britain and the Continent. For instance, from 8 to 10 a.m. Berlin has a lot of traffic to send to London, and London has little to send to Berlin. From 10 a.m. to noon the flow is about equal in each direction. Berlin begins to slacken down after midday and remains slack till after 4 p.m. After noon London sends more than Berlin. On fish circuits in Great Britain, Grimsby and Aberdeen are very busy from 7 a.m. onwards, both with railing fish and prices. Queenstown and other big ports are busy all night with arrivals and departures of boats. Each boat arrival at Queenstown means, perhaps, 100 messages to large hotels and friends.

Multiple Address Messages.

It frequently happens that the same telegram has to be sent to a number of different people. These are known as multiple address messages. One source of such messages is pigeon-flying. This sport is very popular in England, and during the pigeon Derby, pigeons are sent from all over the country to one place and liberated. As many as 900 or 1,000 telegrams are sent off to the various owners of the birds, mentioning the time of liberation and the direction of the wind. The text of these messages is the same in all ; the addresses only vary. These addresses are usually given to the Post Office a day or two beforehand. They are received in the head telegraph office in London and copied out on thin telegraph forms and kept in readiness. At the time when the pigeons are liberated a single telegram comes through to the London telegraph authorities, who promptly start manifolding it in batches of six or more on the previously addressed message forms. The filled-in messages are then sent from London by telegraph all over the country to the given addresses. Obviously a printing telegraph cannot do this class of work. Multiple address messages of 1,000 addresses are not common ; but messages of from 6 to 12 addresses are frequent enough, especially

from the Channel Islands. It is difficult to see how they could be dealt with by a printing telegraph. Sending the address and text of each separately would be too slow. The addresses could be sent easily enough, but this text would have to be typed or written in by hand with the aid of carbon paper, or hectographed. Racing and betting telegrams are also responsible for many multiple address messages. The number of telegrams sent out by tipsters and betting men in Great Britain is extraordinary. A tipster, say in London, who has been lucky enough to select two or three winning horses, advertises the fact, and so gets many hundreds of clients, to whom he sends out a multiple address message, recommending them to bet on several horses as certain winners. The addresses come through and then the text, and this text is manifolded on the addressed forms. If there was any regularity about this procedure some printing telegraph arrangement might, perhaps, be devised to deal with it by modern methods of duplicating, but the tipster's profession is precarious. During a lucky week his *clientèle* may swell into hundreds, and then after a few bad selections of horses the number of his clients will dwindle away to nothing. The tipster keeps quiet for a week or two, until his bad advice has been forgotten, or changes his address and makes another lucky hit in "spotting winners." Then up goes his reputation once more, and once more multiple address messages go to hundreds of clients. That is hopeless from a printing telegraph point of view. Hand work must come in in such cases. One of the most famous multiple address messages was that sent out by the London *Times* when selling the "Encyclopædia Britannica." That ran into 24,000 addresses.

TRAFFIC ARRANGEMENTS AND HOURS OF DUTY.

The telegraph service in all large Administrations is very highly organised, and printing telegraphs introduce considerable changes, which cannot be effected without a good deal of trouble. Telegraph work is very irregular, and it is at its maximum only for a few hours a day, at least in Western European countries. Consequently it requires very ingenious and complicated arrangements of the hours of duty of the operators, and close attention to the average number of messages per operator, per hour (or more briefly, "operator averages"), to prevent waste of labour under such conditions. If, on an average of, say, three days' work, there is found to be extra pressure of traffic between two towns, then an extra channel is opened, or *vice versâ* a channel may be closed. Men are shifted back or forward as the traffic requires. If two wires do not supply enough work for two operators, then one operator has to attend to the two wires, and so on. Then there may be a rush of work in the news division, and men have to be drafted in from other divisions to cope with it. Or sometimes, when there is heavy pressure of traffic between two towns, traffic may have to be diverted through other towns. Various divisions of the telegraph office in London help

one another in this way. Printing telegraphs necessarily vary these arrangements considerably. In countries like Great Britain, with very heavy telegraph traffic over short distances between busy towns, the traffic arrangements are very complicated indeed. Important sittings of Parliament also involve heavy news work, and there are often late sittings. All this upsets arrangements. There is also constant pressure from above on the supervising staff to maintain good operator averages. The officials have, therefore, worries enough to keep the old-established routines going, without having them upset by new printing telegraph systems. Fortunately, the Murray automatic system fitted in rather well with the habits of the British telegraph officials, who had had long experience of the Wheatstone automatic. The best methods of organising traffic for an automatic system were familiar to them. Some of the Wheatstone customs were a hindrance, but on the whole the Wheatstone experience was very beneficial.

On the Continent of Europe there has been long experience with the Hughes printing telegraph, which handles the bulk of Continental traffic. There are plenty of skilled mechanics, and all telegraph offices of any size at all are provided with a repair workshop. On the other hand, the use of the Hughes printing telegraph at once limits the employment of new printing telegraphs unless they are of quite exceptional merit. Also in France the Baudot printing telegraph holds the field against any other system. Each country has its own arrangements and methods of dealing with telegraph traffic. The class of operator employed in each country also varies greatly. In America and Great Britain and Russia, and indeed in most other countries, female as well as male operators are largely employed. In Germany, on the other hand, male operators are chiefly employed, and they include many old soldiers, good reliable men, but as a rule not so rapid as men who have learnt telegraph work early in life. In Great Britain no record is kept of the messages as transmitted at the sending station (except the original messages as handed in), but most countries on the Continent of Europe insist on a "home record." The Murray keyboard perforator tape is a good home record, and is accepted for this purpose by the German and other Administrations using the Murray apparatus. Keeping a home record, however, involves extra labour to wind up the tape.

In Germany the Hughes methods were an assistance to the Murray automatic system, and also a hindrance, just as in England the Wheatstone system was a help and a hindrance. With the Hughes, which prints its messages on a tape, it is necessary to insert special signals to distinguish the preamble from the address and the address from the text, and the text from the signature, and also to indicate the end of each message. With a page-printing telegraph these printed special symbols are not necessary, as the printing machine does the work automatically; but it was only gradually that these Hughes signals were abolished in the case of the Murray system, and not until it was

demonstrated that Hughes methods applied to the Murray automatic system caused a distinct loss of time and labour. Hughes operators, when put to work on the Murray keyboards, found it difficult to break away from their Hughes habits. In England the change of telegraph forms from two kinds (one for S and one for X messages) to one form for both kinds of messages was made without difficulty, except in regard to the large "TO" that used to be printed at the beginning of the address in British telegrams. This "TO" seemed to be sacred, in spite of the fact that page-printing telegraphs must necessarily often print the address right through the "TO." After several years the G.P.O. finally agreed to omit the precious word. Other far more radical changes were agreed to quickly and without demur. These trifles all adjust themselves in time.

The differing conditions even in neighbouring countries in Europe are surprising. In Germany the operators are, by law, responsible to the outside public for mistakes, and may be sued individually for damages. The Government is not responsible. To safeguard themselves the operators tried an insurance scheme; but as soon as the existence of the insurance fund became known to the outside public, actions for damages became numerous and the fund soon faded away, so the writer was informed in Berlin. Now the operators prefer to trust to a personal appeal, and, as they have to deal mostly with good fellows, the appeal is generally successful. The possibility, however, is unpleasant, and checking telegrams very carefully is universal in Germany, and operators are never blamed for going slow. You can rely on a German telegram being accurate. Mistakes occur, but they are few compared with those in English-speaking countries. In Austria the individual operator is not liable for damages for mistakes. Also the "tantieme," or bonus system, prevails. They get a percentage on the number of messages they transmit. The same system is in force in the United States. The result is the "Tantieme Jäger" or percentage hunter, and the Austrian Tantieme Jäger is the nightmare of the careful German operator who wants to go slow to avoid mistakes. In Russia there is a much more pleasant and easy-going state of affairs, and afternoon tea is an established institution, as in London. In Russia the telegraph traffic flows along majestically like one of Russia's own rivers, without haste but without rest. Russia is a continent with day in the east while it is night in the west. Hence long-distance traffic in Russia flows continuously right round the clock. On such long lines there is no extreme urgency about transmission of telegrams in a few minutes. If they are delayed for an hour or so in transmission over 2,000 or 3,000 miles there is no harm done. This also tends to equalise the flow of the traffic. These conditions are very favourable for printing telegraphs, and during the last few years Russia has gone in extensively for machine telegraphy, with quite satisfactory results. On the other hand, on the long Russian lines a printing telegraph has to work through much longer hours than in England. In England there is very little telegraph traffic at night

except press messages, and the bulk of the traffic clusters round the hours between 10 a.m. and 3 p.m. The result is that a printing telegraph in England can only be used to its full capacity for a few hours a day. In Russia the machines have to work fully fourteen hours a day on many lines. They have, therefore, in many cases, to do about three times as much work per day as in England.

INTERNATIONAL CIRCUIT TROUBLES.

In Western Europe there are two very serious handicaps on telegraphy, and therefore on printing telegraphy. These are: (1) The comparatively small areas over which undivided authority exists, and (2) the differences in language. The prime conditions for extensive use of telegraphy are a large and well-educated population speaking one language and spread over a continental area. These conditions exist to a high degree in the United States of America, and in the United States telegraphy is making remarkable progress, in spite of the competition of the telephone. In fact, the telephone assists. There is also one language and a continental area in Canada, Russia, Australia, Brazil, the Argentine, and South Africa. When these new giant world States have grown up, telegraphy will take on a very different aspect from what it has now. Telegraph traffic will be enormous; printing telegraph inventors will come into their own, and there will be printing telegraph millionaires in those days. Meanwhile the printing telegraph inventor has to wear the mended shoe, because the growth of the telegraph service is cramped by the smallness of European States like England, France, and Germany, and by the differences of language, and by the division of authority. Differences of language and political divisions have confined trade in Europe within comparatively small national boundaries, and long-distance telegraph traffic in Europe is very small compared, for instance, with the United States.

Apart from the language difficulty, the worst evil on these international European circuits is divided authority. The operators at each end of these circuits are quite independent of each other, and the officials at one end have no control over the other end of the line. Under such conditions a certain amount of friction and lack of harmony is inevitable. The London operators, for instance, say that they have always to give way and do what the Continental operators want. The Continental operators, on the other hand, say that the London operators are the most obstinate people in the world. In spite of this, or perhaps because of this, there is much politeness on these international circuits, and frequent "Yes, Mister," and "No, Mister." To such an extent is this carried that a London operator remarked indignantly to the writer: "Every R Q means a sermon with these foreigners and half-an-hour's delay." If the European international lines came under the control of an American manager he would issue an order something like this. "Don't clog the wires with polite expres-

sions. Take them for granted or send them by post. *Every signal costs money.*" Unfortunately Anglo-Saxon brusqueness gives offence on the Continent. The one desire of the English and American telegraph operators is to move the traffic, and they drop all polite formalities. The Germans are tending in the same direction nowadays, but the Latin nations stand on their dignity, and are very "touchy." London operators have been schooled into a knowledge of this peculiarity and make the necessary allowances for it; but there is a story that Liverpool got a direct Hughes wire to a certain French town. Liverpool started speaking to the operator in the French town as Liverpool was in the habit of speaking to London. The result was silence. The French operator simply left the circuit for three days. Liverpool had to send its messages *viâ* London as of old, and had to ask London to mediate. London was told by the French town that when competent operators were sent from London to Liverpool to work the direct wire, the French town would resume direct telegraphic intercourse with Liverpool. That is a characteristic experience on a good many Continental wires, and it does not smooth the path of the printing telegraph inventor.

Alphabetical Troubles.

Not only is there great difficulty in getting a printing telegraph to work perfectly and to save time, labour, and telegraph line; but also, if it is to go into extensive use, it must have sufficient elasticity to fit in with the requirements of various telegraph administrations. Reference has already been made to the varying conditions to be found in different parts of Europe. One of the most serious difficulties arises out of lack of uniformity in language. The general effects of the limits imposed by diversities of language have already been referred to, but there is one special aspect of this matter that needs further attention. Out of the varying languages spring varying alphabets, and a printing telegraph suitable for use in English-speaking countries is by no means suitable forthwith for countries using another language. Out of these varying alphabets spring up several mechanical troubles. One of the chief mechanical problems in a printing telegraph is the same as in a typewriter, namely, to bring any one of a given number of type to one printing point and to return it to its position of rest in the shortest possible time. The size of the type which it is convenient to read and which prints clearly under typewriter conditions has an important bearing on the question. There are fairly definite limitations in regard to the size of the type. There are also limitations to the number of type if operation is not to be very slow. A typewriter, for instance, with 10,000 different characters would have typebars 15 ft. long, or if it was a type-wheel machine the type-wheel would be over 10 ft. in diameter. Typewriters seldom have more than 90 characters. That is about the limit of what is practicable. Serious mechanical difficulties arise with the introduction of any greater number of characters. With printing telegraphs there are still further limita-

tions arising out of the codes of signals. These impose a practical limit of about 50 to 60 characters. For instance, with the 5-unit alphabet used in the Baudot and the Murray systems, there are 32 possible signal groups (permutations of five things taken, 1, 2, 3, 4, and 5 at a time). By using a shift key this number can be doubled, but as the space signal and two or three operation signals have to be provided for there are practically about 54 characters that it is possible to transmit with the 5-unit alphabet. A second shift key may be used, giving about 120 different characters, but two shifts entail too much loss of time in operation, and it is very desirable to adhere to one shift only. As we are confined to about 54 characters, and as we have to provide 10 numerals and about 15 punctuation marks and other figures, it is not practicable to provide both capitals and small letters. It is usual in printing telegraphs to employ capital letters only, but the German Telegraph Administration prefers small letters only, scientific investigation having shown that small letters are more distinct and easily read than capital letters. There is no difficulty in providing for that difference in practice; but when we are limited to 54 characters, and when each country requires some special character—usually several accented letters—the difficulty in the case of a printing telegraph that aspires to be used internationally becomes serious.

Looking through the alphabets of the leading languages of Europe (excluding Russia, which has a special alphabet of its own) we find the following characters :—

Common to All.

a b c d e f g h i i k l m n o p q r s t u v w x y z 1 2 3 4 5 6 7 8 9 0

. , ? — ( ) ' " / %

Special Characters.

Germany.—The three modified vowels *ä, ö, ü,* although in general use in all printed matter in Germany, are not employed in the German telegraph service, *ae, oe* and *ue* being used instead. Germany follows closely the International Telegraph Convention list of characters, and therefore requires—

: & ! ; =

Austria.—Special requirements in Austria are—

š ż ř ň č # !

Hungary.—In the Hungarian language there are a variety of accented letters, amongst others the following :—

ő ó ö ú é á

Italy.—The grave accent is used with all the vowels in Italy, but in the telegraph service only *à è ò ù* are employed, and these only in Morse. For the Hughes the accents are dropped, and for the

Baudot the Baudot characters are employed. *é* is practically the only accented letter actually employed. It is substituted for *w* in Italy and in the Italian telegraph service to France.

France.—The accented letters *é è à* are common in French words, but only *é* is used in telegrams. In the Baudot system, in addition to the letters and numerals and the International Convention punctuation marks, there are a number of special characters as follows :—

é F̲ H̲ O̲ N^{o.} ✱ '

Norway.—The telegraphic alphabet employed in Norway calls for—

: *æ ö é* " = !

Sweden.—The telegraphic alphabet used in Sweden provides for—

å ä ö : ; *é* !

Spain.—The International Telegraph Convention alphabet is closely followed in Spain. The Spanish accented vowels are the reverse of the Italian and carry the acute accent—

á é í ó ú ñ

but they are not used in telegrams, except *é*, and it is only on very rare occasions that it is necessary to explain at the bottom of a message that a vowel in a certain word is accented. *n* is usually employed for *ñ*.

England.—The confusion between fractions and shillings through the use of the fraction stroke / has recently led to the employment in the British telegraph service of the special character | as the shilling stroke, the sloping / being kept for fractions. A special character has also been introduced to separate whole numbers from fractions thus, 2⁀3/8. Otherwise there are no special characters required in English telegrams, and there are no accents in the English alphabet.

International Convention.—The alphabet provided by the International Telegraph Convention, in additional to the 26 letters of the alphabet and 10 numerals, employs the following punctuation and other marks :—

. , ; : ? ! ' " + — / = ( ) & ×

Several of these characters are quite useless for telegraphic purposes, as they are never required. No one ever wants to telegraph a semicolon, for instance. The Administrations, however, adhere to the Convention more or less and the characters have to be provided.

Cable Companies.—Most of the cable companies provide Morse signals for—

ä á or *å é ñ ö ü* ! ; :

but they are seldom required.

Esperanto.—The Esperanto alphabet only calls for notice as an amusing curiosity. It employs the circumflex accented letters—

ĉ ĝ ĥ ĵ ŝ and *ŭ*.

One of the chief advantages of an international language would be for international telegrams, but it is not quite clear how these accented letters are to be telegraphed.

Russia.—The Russian language is provided with a commodious alphabet of its own with 36 characters. It is impossible to send telegrams in this alphabet outside of Russia.

Japan.—The Japanese language is represented by an alphabet of 48 letters, 10 numerals, 7 punctuation and other marks, in all 65 characters. As in the case of the Russian alphabet, it is impossible to send telegrams in the Japanese alphabet outside of Japan.

Summing up, it will be seen that any printing telegraph system aspiring to suit merely the leading European languages, excluding Russia, would have to provide—

26 ordinary letters of the alphabet.
10 numerals.
18 punctuation marks.
16 accented letters and other special characters (probably more than 16).

—

70 characters in all.

In the Murray systems the difficulty was overcome by providing an international keyboard and reserving seven characters for national use, as in Fig. 1.

The secondary positions on key buttons S D F G H J K are reserved for national characters to be used in telegrams not passing out of one country. The idea is that a telegram using only the international characters shown in the diagram can be transmitted and retransmitted automatically on the Murray systems on Murray circuits on any international lines to any point required—for instance, from Dublin through London and Berlin on to St. Petersburg.

This keyboard arrangement worked satisfactorily until the Murray system was installed in Sweden. It was then found that *w x* and *y* are seldom used in Sweden, and *å ä* and *ö* are frequently used. Owing to the loss of time arising from putting them in the secondary positions for national characters, it was decided to put these accented letters in the place of *w x* and *y* in the primary positions, *w x* and *y* going into secondary positions. This has made a break—the only break, so far, in the internationality of the Murray systems. In Norway they adhere to the international arrangement of the Murray keyboard.

In Russia the alphabet difficulty appeared at first sight to be insurmountable, because a printing telegraph in Russia must print both Roman and Russian letters. As there are 26 Roman letters and 36 Russian and 10 numerals, and about 15 other necessary figures and punctuation marks, we have about 87 characters in all to be provided. The Hughes and Baudot systems, both of which are extensively used in Russia, overcame the difficulty by providing two distinct type-wheels,

one with Roman type and the other with Russian type. When in a Russian message a word in Roman letters has to be transmitted, the sending operator has a special call to attract the attention of the receiving operator, who then shifts the type-wheels on their spindle so as to bring the Roman letter-wheel into printing position, and *vice versâ.* This rather clumsy device serves its purpose well, but it is not applicable in the case of a typebar typewriter like that used in the Murray automatic system. It is also not automatic. In the case of the Murray automatic system the difficulty was overcome as follows :—

Out of 36 letters in the Russian alphabet only about 33 are really necessary, and one of these bI, can be printed by using two other letters. This leaves 32 characters to be provided ; 13 of these are the same as the Roman alphabet though representing different sounds. H, for instance, in Russian represents the Roman N ; P is R and C is S. This reduced the number of characters required to print both Russian

INTERNATIONAL MURRAY KEYBOARD

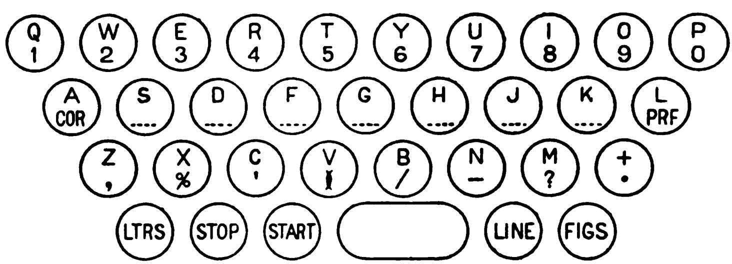


FIG. 1.

and Roman to 64. This was practicable, and it was provided by two shift keys. One key shifts from letters to figures and the other key shifts from Russian to Roman letters. The selecting mechanism is necessarily very intricate to meet such requirements, but once it is made it works well and easily, and it is automatic—that is to say, the printing of Russian or Roman letters and figures at the distant station is done entirely by the sending operator.

The Russian Murray keyboard is shown in Fig. 2.

One way out of these difficulties would be to use the 6-unit alphabet instead of the 5-unit alphabet. This would provide 64 signals, and 64 keys and no shift keys. It would meet the requirements of nearly all languages, but it has the serious drawbacks that it would increase the complexity of the apparatus in the ratio of 5 to 6, and double the size of the keyboard and the number of keys ; and worst of all, it would increase the number of signals on the line from a trifle over five to six, an increase of nearly 20 per cent. This would be a distinct handicap in the case of long or

difficult lines, but it would still be shorter than the Morse alphabet in the ratio of 6 to 8, in the case of the Murray automatic system. In the case of the Murray and the Baudot multiplex systems correcting and retardation segments would bring up the length of the signals nearly to the level of the Morse. It would also necessitate the abandonment of the use of a letter-shift printing mechanism corresponding to the shift-key typewriters. This would practically double the complexity of the printing mechanism in the case of the multiplex. The full non-shift keyboard with a separate key for each character is undoubtedly a little quicker than the shift-key keyboard; but the gain is only about 5 per cent., and most printing telegraphs have adopted the shift-key arrangement in preference to the extra complexity of mechanism and reduced line efficiency of the "one key one character" arrangement with its longer code of signals. The same problem confronts the typewriter manufacturers. The full

RUSSIAN MURRAY KEYBOARD

FIG. 2.

keyboard non-shift key typewriters are undoubtedly somewhat more rapid in operation than the shift-key machines, but the number of shift-key typewriters, especially those of the Remington pattern, greatly exceeds the number of the full keyboard typewriters.

In the case of Japan, the alphabet difficulties are more serious even than in Russia, and the 6-unit, or some correspondently lengthened code of signals, will be a necessity. In Japan, Roman letters are not in use, and there is a special Japanese alphabet of 48 letters, 10 Arabic numerals, and 7 punctuation marks and accents, in all 65 characters as a minimum. Also, instead of reading horizontally from left to right, the Japanese read the lines vertically from top to bottom of the page and pass from line to line from right to left. It is exactly like reading a European book turned round to the right till the lines are vertical. A still more formidable difficulty is that the Japanese alphabet is used mixed up with Chinese ideographs. For this reason, up to the present, it has not been possible even to use typewriters in Japan. Some books are printed in Japan with

the Japanese alphabet only, but it makes the books very voluminous. The Chinese ideographs are really a system of shorthand, one character representing one word. This greatly reduces the bulk of a book. With the exceptions of the ten ideographs, which we call Arabic numerals, it is impossible to telegraph ideographs, because we cannot spell ideographs, and spelling is the foundation of telegraphy. For telegraphic purposes in Japan it was therefore necessary to use the Japanese alphabet only, and the existence of a Japanese alphabet was found to be a very great assistance in the rapid spread of telegraphy in Japan. In addition to the 48 Japanese letters there are also 25 umlaut, or accented characters. Fortunately, as the accents are above the letters and as the letters are written in vertical columns, the accent can be printed as a separate character before and therefore above the letter. The difficulties of adapting a printing telegraph to such an alphabet are very great, and up to the present the only printing telegraphs in use in Japan are a few stock-tickers, including the Siemens and Halske Ferndrucker. The problem is very difficult but not insoluble. Instead of the 5-unit alphabet, the 6-unit alphabet, or some other corresponding lengthened alphabet or code of signals will be required. The 6-unit alphabet and a shift-key will give the required range of characters. Fortunately also the printing in vertical lines and reading the succession of lines from right to left can be provided for by inserting the message form in the typewriter in the usual way, but arranging the type to print horizontally instead of vertically, for instance, thus :—

NOW IS THE TIME

FOR ALL GOOD MEN

1741
9513
9156

Also it is obvious, when once we think about it, that the Arabic numerals can be added horizontally just as easily as vertically. We read figures horizontally and add them vertically. The Japanese read figures vertically and add them horizontally. For instance, they write the year 1910 thus :—

1
9
1
0

In the case of China there are at least several thousand ideographic characters required for ordinary intercourse and there is no alphabet. Telegraphy of any kind, to say nothing of printing telegraphy, would be impossible under such conditions, but by numbering the ideographs and by telegraphing the numbers, the difficulty is converted into one of coding and decoding at the sending and receiving stations. So

far as telegraphy is concerned, under such circumstances only the ten numerals are needed, and an extremely simple printing telegraph with only ten numerals and one or two other characters, and using the four-unit alphabet with 16 permutations, will meet all requirements. Printing telegraph apparatus to meet these requirements will be cheap, simple, and very rapid and reliable.

Of course, the alphabet difficulty only arises in the case of a printing telegraph working on an internatioual circuit connecting two countries speaking different languages. It is chiefly in Europe, with its great variety of important languages, that the trouble exists. A printing telegraph in Europe to be really international must meet the requirements of all the leading European languages. When an ocean intervenes, printing telegraph communication is impossible at present, and the problem of conformity to two different alphabets does not arise. By a printing telegraph to be used internationally is meant a printing telegraph like the Murray automatic or multiplex that can retransmit messages automatically from a received perforated tape. Obviously, for such retransmission to be possible all over Europe, an international keyboard must be employed applicable to all the nations of Europe. That is what the Murray systems have attempted to provide, as shown in Fig 1.

In the case of Great Britain, there are no accented letters, but there is a very curious alphabetical difficulty arising out of the similarity in the methods of writing shillings and pence and fractions. It is an insignificant little trifle, but it has caused much trouble to the British Telegraph Administration and serious loss to merchants. For instance, 7/8 is 7s. 8d. or the fraction $\frac{7}{8}$. The difficulty is to discover a method of avoiding the confusion. It does not occur in the case of countries not using British coinage, and international circuits between Great Britain and the Continent of Europe cannot conform to British requirements, as they are bound by the International Telegraph Convention, which provides for the use of the oblique stroke as the fraction sign and not as the shilling stroke. The Hughes, on which practically all British-Continental traffic is carried, represents fractions in this way, namely, 7/8. As an illustration of the confusion which exists, 3 7/8 may be read as 37s. 8d. or as $3\frac{7}{8}$. Also 37/1/2 may be 37s. ½d. or £37 1s. 2d. To get over the difficulty, in the case of the Morse key and sounder a new Morse signal was introduced to indicate a break between the whole number and the fraction. This signal used to be two *M*'s — —   — —   It is now — — — —   This is liable to be confused with — — — — — which represents the cipher o. Hence the fraction 3 7/8 is liable to become 307/8. Again, the new signal for the Morse oblique stroke is confusing. It used to be three *S*'s - - -   - - -   - - -   Now it is - — — — — and is liable to be sent -   — — — — which is *ex*, and the fraction becomes 307 *ex* 8.

The following is an actual case of error in a message from abroad. The group of figures was as follows: $2\frac{5}{16}$, $3\frac{1}{4}$, $4\frac{3}{8}$, $56\frac{1}{2}$. It was stated to be one group, and it was received thus: 25/1631/443/8561/2.

An actual case of loss arising from this confusion occurred in the case of the following message: "Buy at 1/2¼," the meaning being "Buy at one shilling and twopence one farthing." It was telegraphed, "Buy at 1/2 1/4." The addressee read it as meaning "Buy at 1s. 2d. to 1s. 4d.," and acted accordingly.

A neat way out of the difficulty in the case of the commoner fractions is the use of what is known as superior figures :—

$^1/ \; ^3/ \; ^5/ \; ^7/ \; ^9/$

These are printed as single characters, and are followed by an ordinary numeral or numerals for the denominator. Thus $^3/8$ is quite obviously a fraction and is distinct from 3/8, which is shillings and pence. It is useless, however, for Continental traffic.

Another suggestion was to use the oblique stroke for fractions, thus, 3/8, in accordance with the Continental practice, and to have a vertical stroke for shillings and pence, thus 3|8. This is a good plan, and it has been adopted by the British Post Office with the addition of a rather absurd fraction tie, thus ⁀. 3s. 8d. is therefore now printed 3|8 and 2s. 2¾d. is printed 2|2⁀3/4. This is certainly not clear to the average man, and it cannot be transmitted at all outside of Great Britain. The single quotation mark used in Norway for the same purpose is better. Also the vertical shilling stroke is liable to be shortened by wear or bad printing till it is liable to be confused with the figure 1. It is rather difficult to see why the Post Office should not insist on the use of the symbols £ s. d., which are universally understood. The only difficulty in the way seems to be the alteration in the count of the number of words. 3/8 counts as one word; 3s. 8d. counts as four words. This fraction difficulty exists even with the Morse key, but printing telegraphs accentuate it.

Printing telegraphs also using capital letters only, the S and D do not look so clear when printed in capitals, thus 3S. 8D.

Code and Cipher Messages.

A serious trouble in telegraphy is the handling of code and cipher messages. Code messages are usually understood to be those containing words apparently meaningless and having no apparent relation to each other, and cipher messages are usually understood to be messages composed of numerals with a secret meaning. In America the practice of contracting well-known words in transmission has come to be known as "coding." The word "code," however, is used here in its well-known international sense. Code messages are the usual form of commercial telegrams oh long lines and cables, while Governments are fond of using cipher messages, usually in groups of five figures. An operator working on a keyboard can easily glance at an ordinary telegram and carry several words in his head while he is typing on the keyboard. With code and cipher

messages this is not possible. This is obvious if we examine a fair average sample of a modern code message such as the following:—

"JYJEPLOLYG AYILUSTMA AVOKKOTUJ JYBOFOZNIT."

Clearly such messages must be very objectionable from a telegraphic point of view, as they impose much greater strain on the attention of the operators than ordinary comprehensible messages. There is, therefore, more liability to error on the part of the sending operator, and there is no context to enable the receiving operator to judge whether he is receiving sense or nonsense. The sending operator has also to work much more slowly with such messages. The cost of transmission is therefore higher. In the case of printing telegraphs code messages are also objectionable, because it is difficult to say, without some experience, whether such a telegram is a code message or a case where the printing mechanism has got out of unison. Fortunately the record made by printing telegraphs when they get out of unison is to a certain extent characteristic, and the fault can in most cases be recognised by an experienced operator.

Keyboards and Keyboard Operating.

With code and cipher messages it is absolutely essential that the operator shall keep his eyes fixed on the message all the time that he is sending, if he is to work rapidly and accurately. With the Morse key and sounder it is an easy matter for an operator to keep his eyes on the copy. With a typewriter keyboard, on the other hand, it would appear at first glance to be very difficult to work without looking at the keyboard. Experience has shown, however, that there is no real difficulty, and that in one month, with proper training, an operator can become an expert in "touch writing" on a typewriter keyboard. That is to say, he can learn within a month to operate rapidly and accurately on a typewriter keyboard without taking his eyes off the message. Code and cipher messages are then as easy to transmit on typewriter keyboards as on the Morse key, with the advantage that a single stroke on a key sends each character.

The same difficulty has been experienced in connection with the use of the ordinary typewriter in telegraphy, and also in using certain Morse transmitting keyboard machines. The typewriter companies long ago discovered the value of "typewriting by touch," and all the record breaking "typists" work in that way. Linotype operators have also discovered the advantage of this method of working. Some years ago it was noticed in New York newspaper offices that certain linotype operators (on piecework) were making considerably higher wages than their fellows. It was discovered that they had learned to operate the very large and complicated linotype keyboard of ninety characters without taking their eyes off the copy. Knowledge of the method soon spread, and "touch operating" on linotypes is now quite general.

Typewriter keyboards are much less formidable. On the piano, of course, playing by touch is essential, and it is much more difficult than on a typewriter. On the latter it is merely a question of systematic instruction and training on the lines long ago found necessary in piano playing.

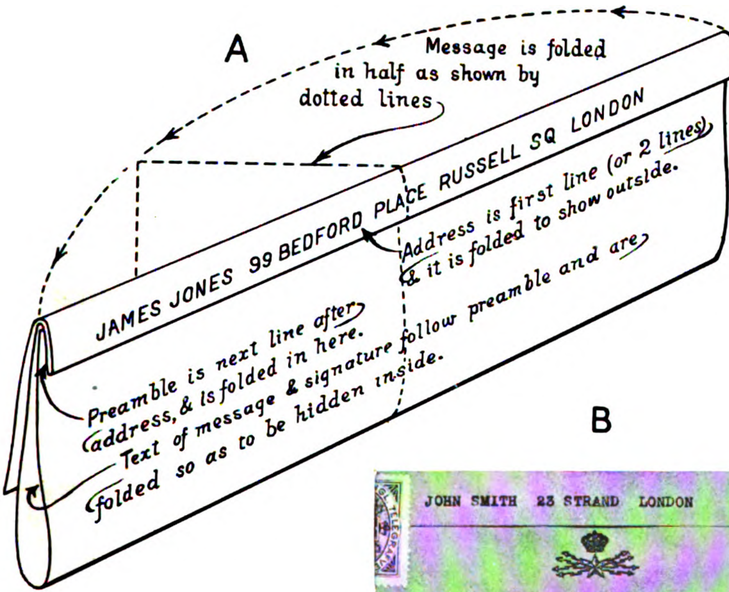
After some months' practice in this way, operators become extremely rapid and accurate. The author has seen 101 successive average British messages of 20 words perforated on a keyboard without a solitary error, and that at the high speed of 90 messages an hour. This is over 2,000 words per hour of complicated matter with many figures and strange words and addresses and personal names. The operator had at the same time to sign the messages and number the perforated tape.

The best operators are those whose sending becomes purely mechanical. Some men will use the Morse key and talk to you at the same time without making a mistake in the message they are sending. Others can whistle a tune and keep time with the "sticks," while punching a message on the Wheatstone puncher, and the perforated message will be free from errors. Operators have been known to work for a whole day on the Morse key without making a single mistake. When this stage of automatic perfection has been reached the operator becomes valuable, especially in the case of printing telegraphs. Such skill reduces the number of errors and of corrections and inquiries, and it is these corrections and inquiries that reduce the output of a telegraph system so much. Every such correction or inquiry means a loss of time on the average equal to the time of transmitting half a message, and more in those cases where the sending operator has to stop to look up the previous message to answer the inquiry. As an illustration of how automatic the work of sending messages becomes, a case was mentioned in the *Telegraph Age* of an operator in an American telegraph office having received the news of Lincoln's assassination over his wire without noticing it. He wrote it out and the news was posted up outside the telegraph office. A great crowd assembled. The telegraph operators were surprised, and on inquiring what the crowd was about learnt that Lincoln was shot. The operator who had received the message, had received it mechanically, and had been entirely unconscious of the substance of the telegram he had written down. That sounds incredible, but it is no surprise to telegraph operators, and it is no surprise to highly skilled shorthand writers. It is exactly in accord with their own experience.

CONTRACTIONS.

With the Morse key an operator can use contractions in sending, because the receiving operator can easily write out the words fully on a typewriter. In the case of a printing telegraph this cannot be done, and if a word is sent over the line in a contracted form it will be printed in the same way. In America contractions are very

A



B

FIG. 3.

A shows Murray Printing Telegraph method of folding telegrams so as to dispense with envelope B shows message completely folded and sealed with a couple of adhesive telegraph stamps used for this purpose only. The advantages are saving of cost of envelopes and saving of time and labour of addressing them.

freely used by operators, and these contractions have presented some slight difficulties to printing telegraph inventors in the United States. In Press messages contractions are also very freely used, and in Press messages to be sent over long ocean cables contractions have been developed into a fine art. All that a printing telegraph can do in such circumstances is to record the contractions.

Envelopes and Addresses.

On the Continent of Europe telegrams are not put in envelopes. They are folded and sealed and sent out in that way. In Germany the address has to be inserted in a special place in the middle of the top of the form. As the preamble comes before the address (in accordance with the terms of the International Telegraph Convention), the preamble has to be printed first, then the address, in Germany, above it, and afterwards the text below it. With a tape printing telegraph like the Hughes, it is easy to put the address at the top, or on the back as in France; but with a page printing telegraph, if it is to work automatically, there cannot be any turning back to put the address in the middle of the top of the message form, and it is quite impossible to print the address on the back as required in France. Fortunately, in the case of the Murray automatic system, as there is a receiving tape on which the message is recorded as perforations before it is printed, there is no difficulty in turning back by hand and printing the address where wanted, without interfering with the reception of the signals over the line. This is the arrangement adopted in Germany with the Murray automatic system, but there is undoubtedly loss of time when the automatic line and page feeds are not fully employed. In any case with a direct-printing page-printer turning back is not possible, and the message must be printed straight ahead as received. Page-printing saves time and labour; but the use of envelopes has a number of drawbacks. With the message folded so as to show the address only, as on the Continent, no envelope is needed, and therefore there is no loss of time and labour in addressing the envelopes, and there is no risk of error in copying the addresses on to the envelopes. Also the cost of envelopes is a considerable item. In Great Britain, for instance, 90 million envelopes are required for telegrams every year. Doing without envelopes would therefore save a considerable sum; but in Great Britain there are a large number of registered addresses, and these compel the writing out of the full address. In many cases, though, the more important registered addresses are printed ready on envelopes. The author devised a method of folding messages to suit page-printing telegraphs (see Fig. 3).

In this arrangement the address is transmitted first and then the preamble. This gets rid of any necessity to turn back, and the message can then be folded so as to show the address only. The conditions, however, are very complicated and in a case of this kind where there are so many conflicting considerations Government Departments are

slow to move. Up to the present the new system of folding has not been used in England or Germany, but it is used in connection with the Murray automatic system in Russia, Sweden, and Norway. It is suitable for any page-printing telegraph, and it appears to be the only possible way of doing without an envelope in the case of messages received on a direct-printing page-printing telegraph.

Mechanical Difficulties.

This record of printing telegraph troubles may be conveniently brought to a close by some reference to the mechanical difficulties arising from the special mechanical problems that have to be solved by the inventors of printing telegraph machinery. Telegraph instruments belong to the class of controlling machines which are of necessity composed of locks, valves, and other ratchet mechanisms. These are the most unsatisfactory of all the kinematical elements, because they do not slide or roll; they strike. Also, their bad character is not improved by the facts that they have almost invariably to be operated by springs, that there is serious wear, and that there are numerous screws and pins which tend to work loose under the continual knocking and vibration inherent in such machines. The theoretical conditions are, in fact, so bad that the satisfactory service obtained from these machines is a matter of surprise. Success has been achieved as the result of attention to a number of practical details. One or two of the most important of these points may be conveniently illustrated by reference to the best known machine of this class, namely, the modern typewriter. A quarter of a century of experience has taught typewriter manufacturers the essentials for success. In the first place, it is a difficult thing to take a screw out of a modern typewriter. Quite a strong wrench with a screwdriver is needed. The screws have been driven absolutely tight home. The screws will also be found to fit well. There are no loose wobbly screws in a good modern typewriter. That is one essential point also in all telegraph machinery. Using only good fitting screws and driving them fast home are elementary and commonplace precautions, but printing telegraph inventors have suffered more from loose screws than from any other single mechanical defect. Another point to be noted about a modern typewriter is the generous size of the springs, and the avoidance of flat springs. Wherever possible steel piano wire springs are used in preference to any other kind. They are also made as large as possible, and there are no sharp bends in them. By using springs ample in size the strain put on them in working is far below their limit of elasticity, and springs are then as satisfactory as any other kind of mechanism. This also is an obvious and elementary point, but it is continually being disregarded by mechanics and inventors. There is also the question of the degree of accuracy required for various parts. Some parts have to fit finely to $\frac{1}{1000}$ of an inch, and other parts, on the other hand, must have

plenty of "air," as the Germans say. The fit must be quite loose. In printing telegraphs as much trouble has been caused by fits being too good as by their not being good enough. Only one other point need be considered. In consequence of their nature, ratchet mechanisms must wear rapidly if they come frequently into action, as they have to do in telegraph machines. The expression "ratchet mechanisms" is used here in the widest sense, to include not only ratchets and pawls, but also valves, electric contacts, and similar mechanisms. There are two remedies. The first is to make the striking surface as large as possible, and of the most refractory materials possible. The second remedy is to make the parts quickly interchangeable, and to provide plenty of cheap spare parts. In a typewriter, for instance, all the wearing parts are interchangeable, and new parts can be quickly and cheaply inserted.

So far as springs and screws are concerned, elementary precautions can be adopted from the outset, but it is not possible to say offhand which parts will wear well in a printing telegraph, and which will wear badly. Only prolonged trials in practical work can develop the weak points, and even when the weak points are known it is not practicable to provide the abundant and cheap supply of interchangeable spare parts until the apparatus has been standardised, and the apparatus cannot be safely standardised until it has been in use for at least two or three years. That puts the printing telegraph inventor in a very difficult position, and it explains why it takes years to develop a printing telegraph up to the stage of practical commercial success. No doubt the telegraph engineer of the future will be able to sit down and design and calculate out a printing telegraph complete and perfect in every detail for any given purpose, just as engineers now design steam engines or electric motors, but it will be a good many years yet before the art of printing telegraphy reaches that degree of perfection.

PART III.

The Murray Printing Telegraph Systems.

In order to illustrate some methods by which the foregoing difficulties have been more or less overcome, the following account is given of the Murray printing telegraph systems. The Murray automatic system has already been described in the paper on "Setting Type by Telegraph,"* and a brief reference only will therefore be made to it, most attention being devoted to the new Murray multiplex page-printing telegraph, of which no description has yet been published.

It may be explained, in the first place, that the Murray printing telegraph systems form a complete printing telegraph organisation and that they comprise—

* *Journal of the Institution of Electrical Engineers*, vol. 24, p. 555, 1905.

The Murray Automatic Page-printing Telegraph, and The Murray Multiplex Page-printing Telegraph.

The two systems, the Murray automatic and the Murray multiplex, have been designed to work together as one whole, the automatic system being best suited for long lines, and the multiplex for lines of average length. The two systems are in a sense complementary to each other. Many of the instruments are the same in both systems, and are interchangeable, the same alphabet or code of signals—the 5-unit Baudot—is used in both, and the perforated tape is the same in both systems, so that a perforated tape message may be transmitted either over a Murray automatic or a Murray multiplex circuit, and it may be reproduced and retransmitted at the receiving station on either system. An important point is that the same keyboard perforator is used on both systems. The standard typewriter arrangement of the keys is followed on the keyboard, and the same characters are used in both systems.

In the Murray automatic system, the messages are first perforated on a strip of paper tape in the Baudot 5-unit alphabet. The perforated tape is then used to transmit the messages by means of an automatic transmitter working on the principle of the Jacquard loom. The speed of transmission of the signals is from 100 to 180 words (600 to 1,080 letters) a minute, and at the receiving station the arriving signals are recorded at the same speed as perforations in a second paper tape, which is an exact replica of the transmitting tape. This reproduced tape at the receiving station then serves to operate an automatic typewriter somewhat on the principle of a mechanical piano. The telegraph line is worked duplex, giving one transmission in each direction simultaneously on the one wire. The received messages are printed in Roman type in page form, at speeds ranging up to about 200 words a minute (20 letters a second). The keyboard perforator for preparing the transmitting tape was described and illustrated in the paper already referred to. The automatic transmitter and the receiving perforator were also described, and there has been no substantial alteration in the construction of these instruments, although there have been many improvements in detail. In the automatic printer a great improvement has been made by the construction of a high-speed typewriter specially designed by the inventor of the system to suit the automatic selecting mechanism. The essential feature of this typewriter is that the typebars are very short, only 2 in. long (50 mm.) from the pivot to the type. This ensures extremely high speed. It is the shortest typebar ever put into a typewriter, the average length of typebars in typewriters being from 3 to 4 in. (75 to 100 mm.). As the moment of inertia varies as the cube of the length of the typebars, the gain in speed with typebars only 2 in. long is from 3 to 8 times. The typebars are also provided with ball-bearings, to ensure free movement and permanent alignment. The illustration in Fig. 4 shows one of these typebars full size. The typebars being so short, it was

necessary to arrange them in a complete circle in order to get room for the required number of 51 characters. As it was very desirable that the operator should be able to see the printing as it proceeded, the circle of type had to be arranged in a vertical plane. Key levers were omitted, as the inertia of key levers interferes with high speed. There are no other special features beyond the fact that the machine is built with unusual strength to stand the strain of the high speed. Fig. 5 is a front elevation of the complete printer, the upper part being the new special typewriter.

Fig. 6 is a back view of the printer.

In a typewriter, or in a page-printing telegraph, there are four motions of the paper as follows:—

Letter-feed.—Short horizontal movement (one letter).
Line-feed.—Long horizontal movement (about 60 to 70 letters).
Column-feed.—Short vertical movement (one line).
Page-feed.—Long vertical movement (one page or message form).

In the Murray automatic printer, the letter, line, and column feeds are entirely automatic, but the page-feed is manually operated, this having been found sufficient for present requirements. The maximum speed that has been reached on this printer is 250 words a minute (25 letters per second). The speed might perhaps be pushed up to 300 words a minute (30 letters per second), but the wear and tear would probably be great at speeds exceeding 200 words a minute. Typewriter companies often claim very high speeds for their machines, but it may be accepted as a fact proved by experience that no hand-operated typewriter on the market to-day will continue to do satisfactory work at a speed greater than 120 words a minute (12 letters per second), and for most typewriters the limit may be taken as 100 words a minute.

In order to prevent interruption of traffic by any stoppage of the apparatus, it is necessary to have reserve machines. With an automatic system this means duplicating the whole of the apparatus. The result is that the Murray automatic system is very expensive, costing at present about £1,200 per circuit, exclusive of royalties. This is a very serious handicap on the use of the Murray automatic. If manufactured in large quantities the cost would come down to about half this amount, but under present telegraph conditions the field for a printing telegraph of this kind is not sufficiently large to require large quantities of the apparatus.

Taking the four factors already referred to, namely, saving of time, labour, line, and office equipment, the Murray automatic system shows to advantage only in respect of saving of line. The cost of office equipment is greater than with the Murray multiplex, there is less saving of labour than with the multiplex, and there may be loss of time if the working arrangements are not good. This is specially the case if the system is worked at a high speed to carry heavy traffic. The

working organisation in this case must be first-class, or there will be a great reduction in the carrying capacity of the system. On long lines, 1,000 miles and over, the saving of time and labour are of much less importance than increase in the carrying capacity of the line, provided always that telegraph traffic is growing rapidly so as to render increase of carrying capacity important. This is the case, for instance, in Russia and other new countries (Russia is practically a new country, Asiatic Russia, at any rate). It is in such conditions that the Murray automatic has decided advantages, as follows :—

1. The alphabet or code of signals that it employs, and the manner of employing it, result in less signalling time per letter than in the case of any other system. The ratio is approximately 5 for the Murray automatic compared with 6 for the Murray and the Baudot multiplex systems, and 8 for the Morse alphabet. This is an advantage of 20 per cent. over the multiplex—an important matter on a long line. The advantage over the Morse alphabet is about 60 per cent.

2. Synchronism is not employed, only isochronism. That is to say, phase is of no importance, but the speed must be right.

3. Governing or control of speed is very quick, so that the right speed is obtained in half a second, and is re-established in half a second if it is momentarily thrown out by a line disturbance.

4. The Murray automatic apparatus is simple—much simpler than any multiplex system.

5. It works very well through the simplest of all repeating stations, namely, the Wheatstone duplex.

6. It works very well and easily with the duplex balance, even on very long lines.

As an illustration of the last point, it may be mentioned that the Murray automatic system is being worked duplex between St. Petersburg and Omsk in Sibèria, with three Wheatstone duplex repeating stations at Riazan, Samara, and Tscheliabinsk. The total length of the line from St. Petersburg to Omsk is 2,224 miles (3,550 kilometres). The wire is iron, and the working speed with the Murray automatic is about 56 to 60 words (336 to 360 letters) per minute. The Wheatstone speed on this line is less than 40 words (240 letters) per minute. Of course, on such a long line there are periods when it is only possible to work simplex, but that duplex working should be commercially practicable on such a circuit is remarkable. Obviously on such a line, with growing telegraph traffic, the one pressing question is increase of the carrying capacity of the line. Saving of time, labour, and office equipment are quite subsidiary.

It will be noticed also that the advantages just enumerated are chiefly advantages for working over long lines. Hardly any of them are of importance on short lines. On lines of moderate length, time and labour saving are the all-important factors, and line saving is quite subordinate. On such lines no automatic system can save so much time and labour as a multiplex system. The splitting up of the line into from four to eight channels greatly facilitates the handling of

traffic. There is less delay on messages, while inquiries and corrections are quickly obtained because of the numerous channels over which inquiries can be made. The speed of each channel being comparative low, one operator on each sending channel can perforate, tape, and attend to his own automatic transmitter. That saves labour compared with the automatic system. Also at the receiving end of the line, the speed of each channel being low, 30 to 50 words a minute, the printers can print direct, and can be made entirely automatic in their actions, thereby saving labour, because one receiving operator can then receive and check as many as 150 messages an hour. On the other hand, on a long line it is not possible to get a number of multiplex channels. Hence on long lines the multiplex loses its chief advantage over the automatic system, and the advantages of the automatic system, already mentioned, then predominate.

On lines not too long to prevent a number of channels being obtained with a multiplex system on one line, the multiplex has the advantage that it can give simultaneous independent channels of communication between several towns connected by a single telegraph wire. This is an arrangement of great practical importance in the case of several towns, none of which alone can keep a telegraph line fully occupied. With an automatic system such an arrangement is not possible. With the automatic system messages may be retransmitted automatically by the received tape, so that various centres can be connected up in this way on one line, but this would only be practicable on long lines connecting important centres. The Murray multiplex, however, now possesses this advantage of being able to retransmit messages from perforated receiving tape.

THE MURRAY MULTIPLEX PAGE-PRINTING TELEGRAPH.

Although the relative advantages and disadvantages of automatic and multiplex printing telegraphs appear to be obvious and are now tolerably familiar to telegraph engineers, this knowledge has only been gradually accumulated during the past few years as the result of prolonged trials of various automatic and multiplex printing telegraphs. The British and German Administrations especially have carried out a very large amount of experimental work with various telegraph systems, including the Murray automatic. The idea of combining the advantages of the automatic and multiplex systems led to the development of the Murray multiplex printing telegraph. It is only about a year since this system passed out of the laboratory stage and arrived at practical success. The Murray automatic system may be said to be based on the Wheatstone automatic transmitter. The Murray automatic transmitter is greatly modified, but the essential principles of the Wheatstone transmitter are embodied in it. In a multiplex system the instrument corresponding to the Wheatstone automatic transmitter is the distributor, and the Murray multiplex system may similarly be said to be founded on the Baudot, because it

has taken the Baudot distributor as its basis. For driving the distributors, however, instead of the Baudot arrangement, the Delany multiplex plan of using the Lacour phonic wheel motor is adopted. Apart from the distributors, the only resemblance between the Baudot and the Murray multiplex is in general principles and in the use of the Baudot alphabet. The Murray multiplex transmitting and printing machines closely resemble the corresponding Murray automatic instruments. Many are indeed identical. The normal speed of the Baudot is 30 words a minute for each transmission. In the Murray multiplex the speed is raised to 40 words a minute, in order to increase the efficiency of the labour at both ends of the line. It is possible that under certain conditions it may prove advantageous to increase the speed still further to 45 or 50 or even 60 words a minute. There are considerable possibilities of both capital and labour saving by such increased speed, and the Murray multiplex has the advantage of easy adjustment of speed over a considerable range from 20 up to 45, and possibly 60 or more words a minute for each transmission or channel.

Like the Baudot and similar systems, the Murray multiplex printing telegraph divides up the line time so as to give several transmissions or channels on one telegraph wire, each at a comparatively low speed suitable for the work of one operator sending and one receiving. Two distributors, identical in design, are employed, one at each end of the telegraph line (station A and station B). The distributor at station A sends out a governing impulse once for each revolution of the contact arm (four revolutions per second for 40 words a minute). This impulse controls the speed and phase of the distributor at station B so as to keep it running in synchronism with the distributor at station A. The distributor used in the Murray multiplex is shown in Fig. 7. This instrument is a "double," giving two simultaneous transmissions working simplex and four when working duplex. The new system may also be worked "triple" or "quadruple," the duplex balance in these cases giving 6 or 8 transmissions simultaneously on one line. Special arrangements have been designed to give up to 6 transmissions in each direction, but it seems unlikely that anything more than quadruple duplex (8 transmissions) will ever be required in practice.

The distributor brush arms are carried directly on the spindle of a phonic wheel motor, which is identical in all respects with the phonic wheel motor employed in the Murray automatic system, and it is driven in the same way by a vibrating reed. There are no gearwheels or governing mechanisms. The commutator and contact arms and brushes are the same as in the Baudot, and the adjustments are the same. The distributor fits on to a wooden base provided with spring contact terminals, so that the machine may be instantly lifted off or replaced. This distributor will work perfectly in conjunction with Baudot distributors and other Baudot apparatus. It has the advantage over the Baudot of being simpler, cheaper, and easier to construct. On the other hand, where Baudot distributors are already in use, the Murray

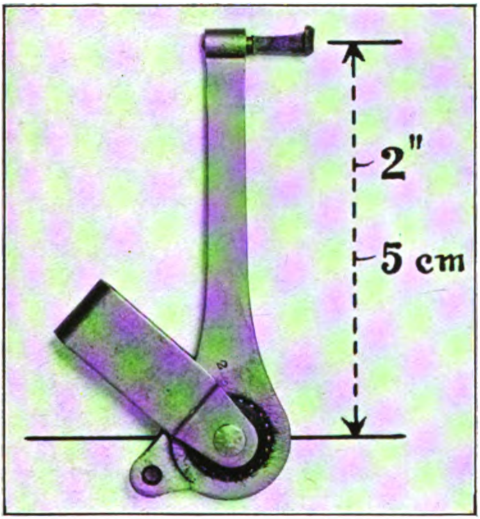


FIG. 4.—Typebar from Murray Automatic High-speed Printer. It is exceptionally short and has ball bearings.

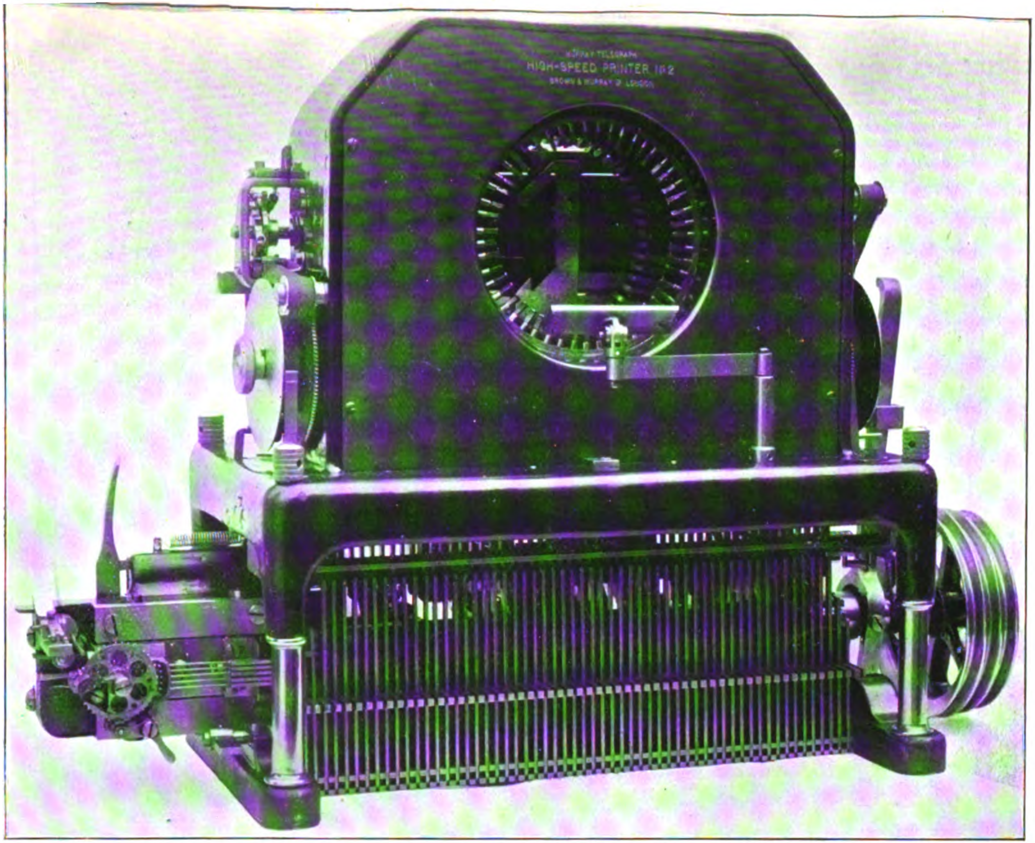


FIG 5.—Front View of the Murray Automatic Printer fitted with the Murray High-speed Typewriter. Speed 1,200 letters per minute.

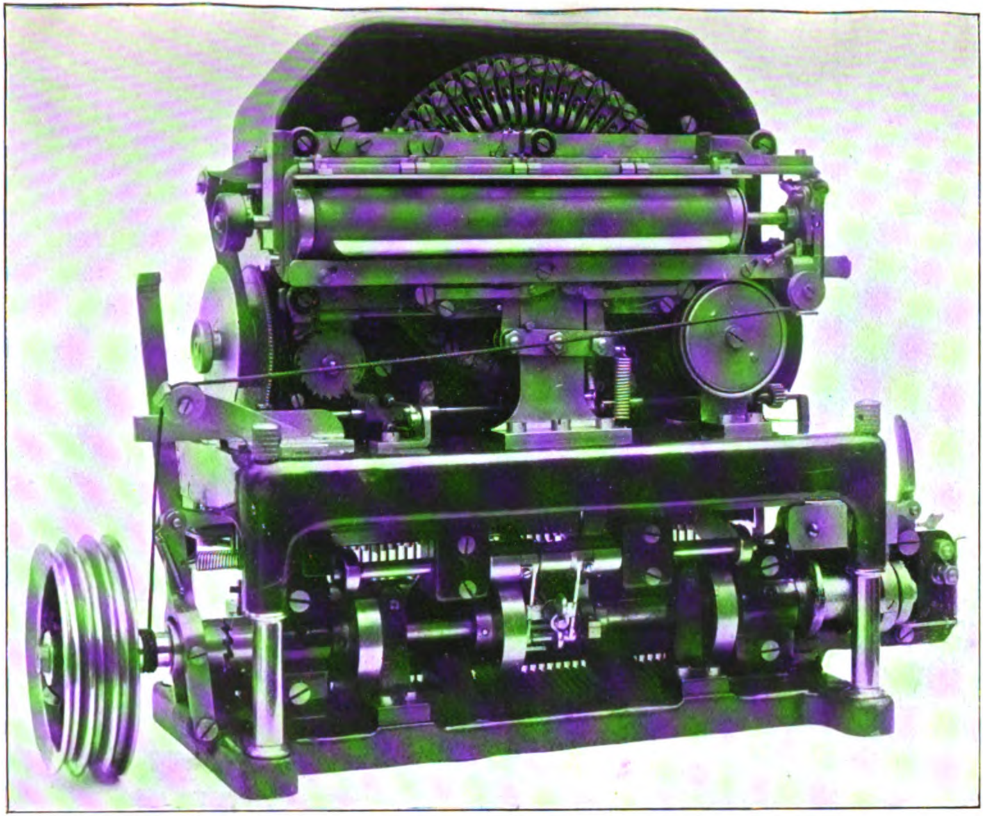


FIG. 6.—Back View of the Murray Automatic Printer with High-speed Typewriter.

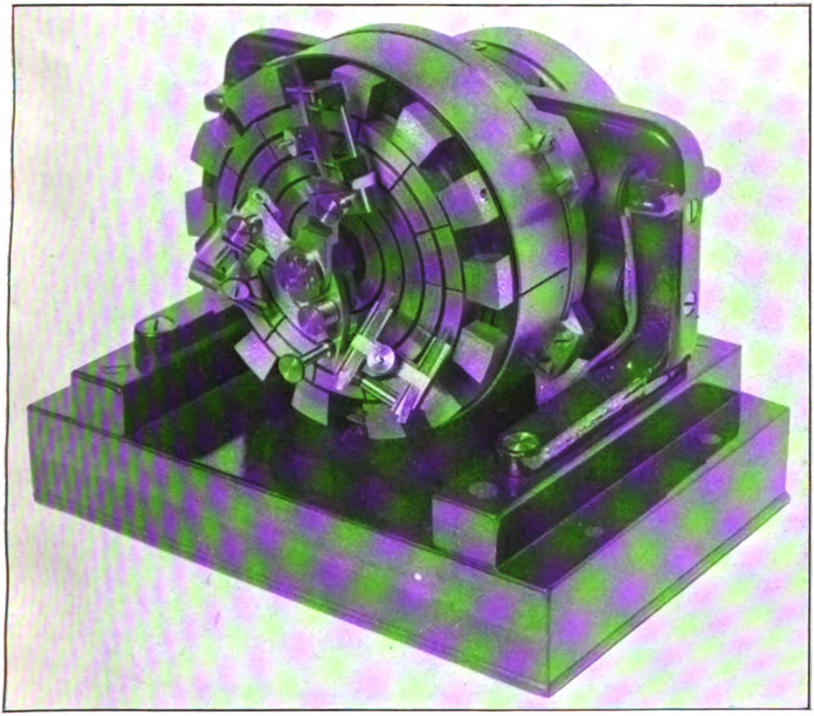


FIG. 7.—Front View of Murray Multiplex Distributor.

multiplex transmitting and printing mechanisms will work excellently with the Baudot distributors. It will be noticed that the Baudot commutator and revolving brush arms take the place of the automatic

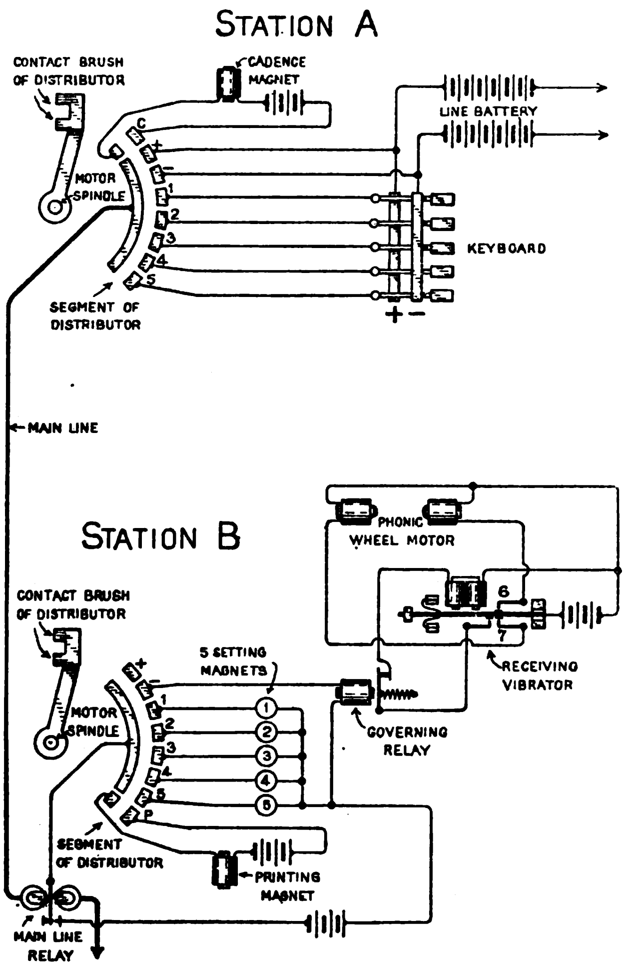


FIG. 8.—Theoretical Diagram of Murray Multiplex.

transmitter driven by the same phonic wheel motor in the Murray automatic system. The Murray multiplex, in fact, combines many features of the Murray automatic and of the Baudot, and a considerable portion of the apparatus, with slight modifications, is interchangeable in all three systems.

The theoretical arrangement of the electrical connections in the Murray multiplex is shown in Fig. 8.

One of the transmitting channels or segments of the distributor and revolving contact brush are shown at each station. For the sake of clearness the other segments for the other transmissions on the same telegraph line are omitted, and for the sake of simplicity the Baudot 5-key transmitter is shown at station A. Also at station A the vibrator and phonic wheel that keep the contact brush of the distributor revolving are omitted. The five transmitting keys at station A normally rest against the top contact bar, which is connected to the negative end of a split battery. The depression of any key breaks contact with the negative bar and puts the key into contact with the positive battery bar. The keys are connected to the contact blocks 1, 2, 3, 4, 5 of the distributor. Various permutations of five positive and negative impulses are transmitted into the line as the distributor arm revolves. In the Baudot system the sending operator has to learn to manipulate these five keys in the 31 different permutations required, and he has to depress the keys at regular intervals, determined by the cadence magnet which is operated by the distributor three times a second, the normal speed of the Baudot being 30 words a minute for each transmission. This method of transmission has the advantage of simplicity of mechanism, but it requires special skill and training on the part of the operator, the work is very monotonous, and the speed is limited to about 30 words a minute.

A typewriter keyboard mechanism to operate these five contacts can be easily designed. Such a machine made by the writer for use with the Murray multiplex is shown in Fig. 9. The five contacts corresponding to the five keys in the diagram, Fig. 8, may be seen on the left of the instrument. There is also a cadence magnet on the left which locks and unlocks the keys to enable them to be depressed at the right moment. On the right there is a letter-counting magnet, which rings a bell at the end of each line of about 60 letters. This is a first-class instrument of its kind, simple, strong, and cheap to make; but as the result of careful practical trials by the British Post Office, automatic tape transmission was found to be so much superior to direct transmission that direct transmission was abandoned altogether, so far as the Murray multiplex is concerned.

Actual trial between London and Birmingham for several weeks showed the advantages of automatic tape transmission over direct transmission to be as follows:—

1. The output of messages per operator per hour is practically doubled as compared with direct transmission.

2. There is less nerve strain on the sending operators, because there is no cadence to be observed.

3. Much more skill is required to work on the direct cadence keyboard than on the keyboard perforator. This has been proved conclusively by practical trials.

4. Provision is made for quick and invisible correction of errors

Fig. 9.—Direct Keyboard Transmitter for Murray Multiplex.

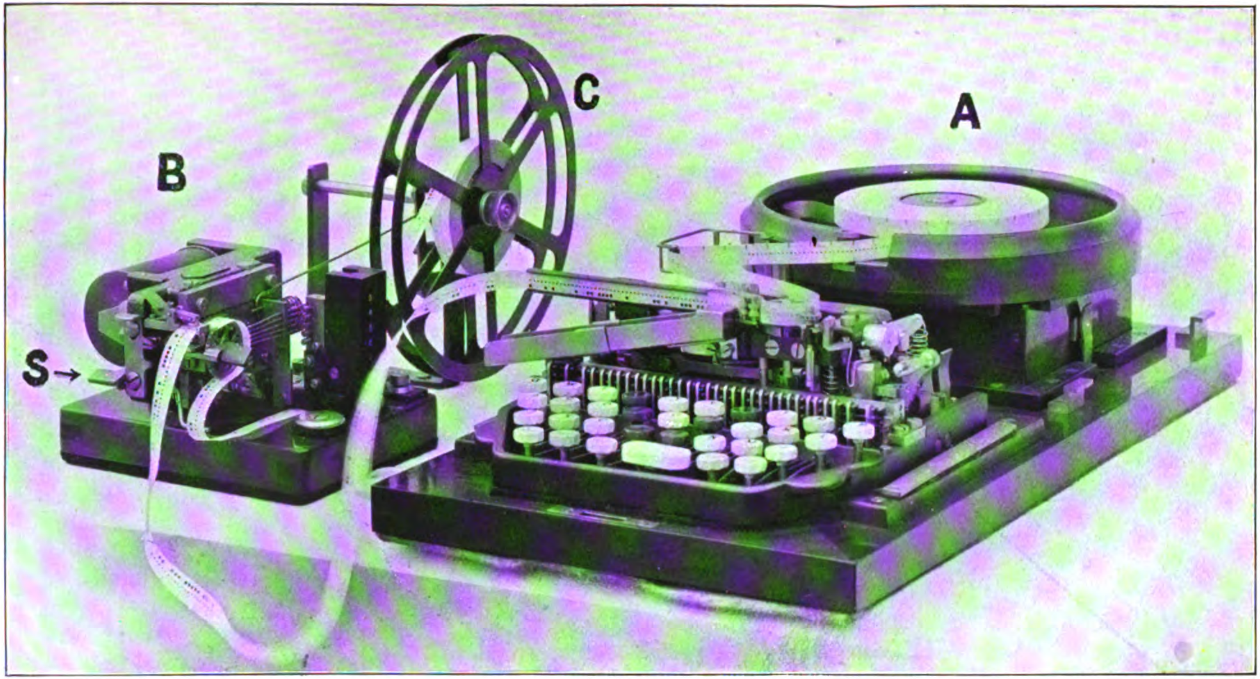


FIG. 10.—Tape Transmission Equipment of Murray Multiplex.

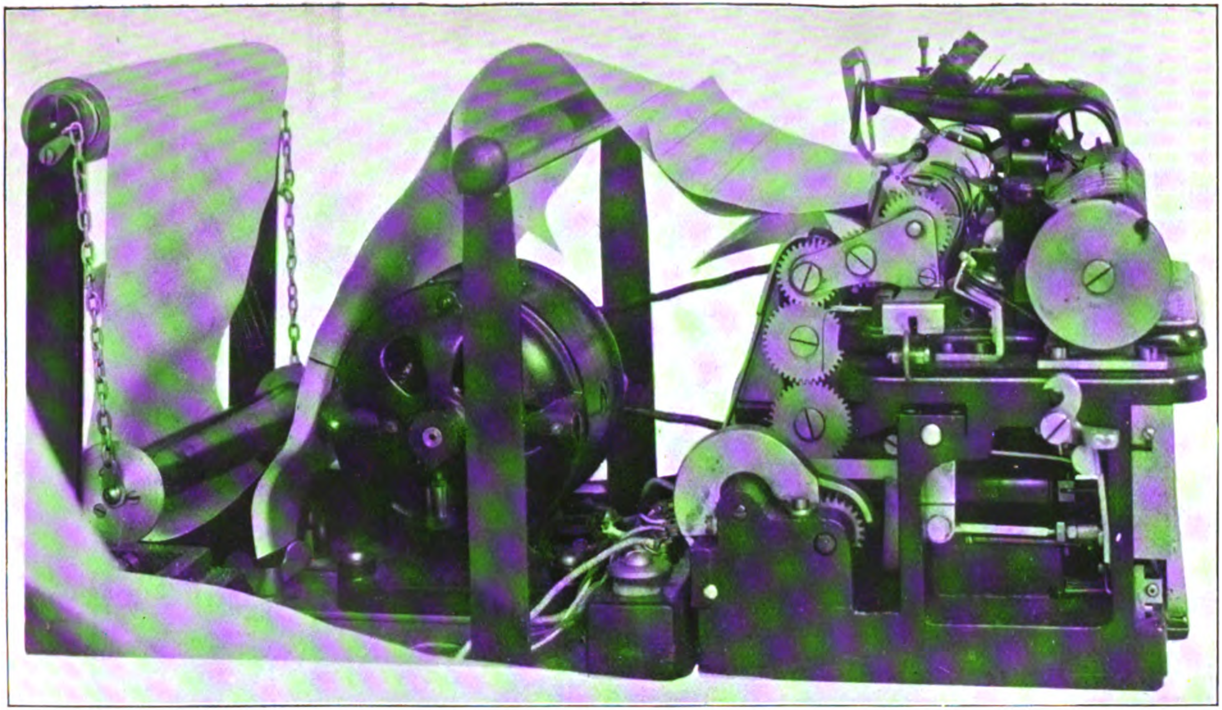


FIG. 11.—Murray Multiplex Printer. Side View.

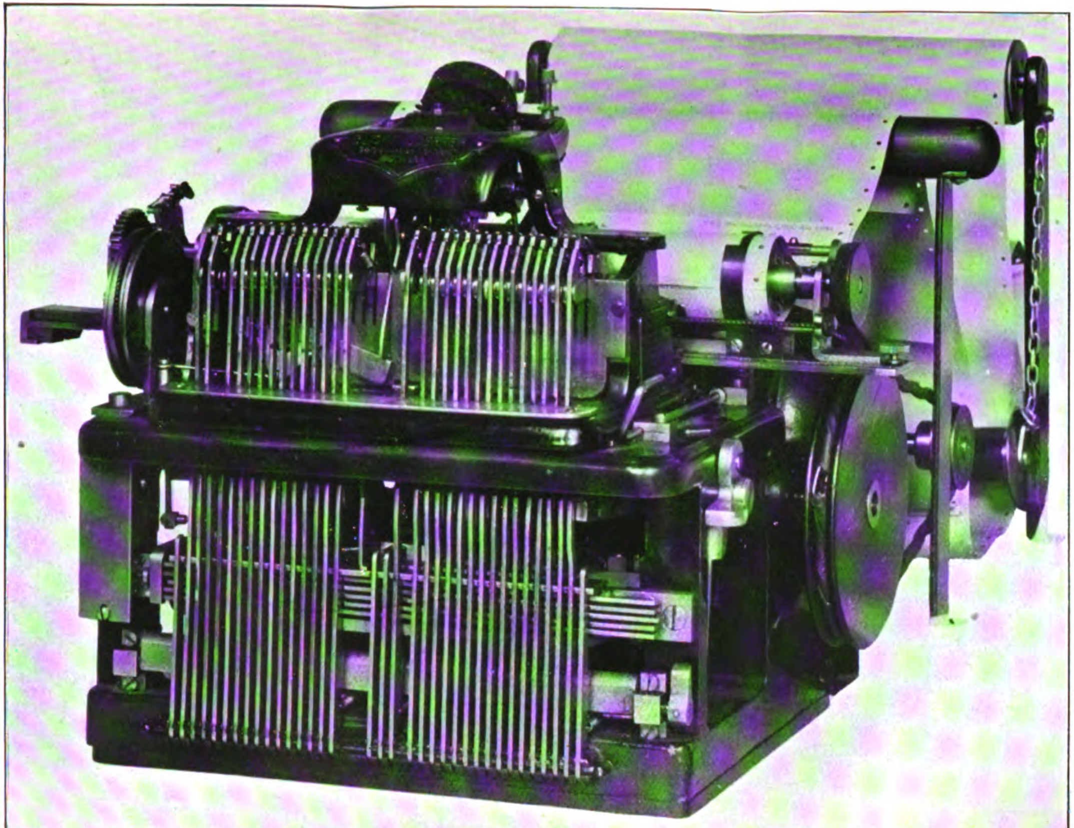


FIG. 12.—Murray Multiplex Printer. Front View.

before transmission in the case of the indirect method of tape transmission in the Murray multiplex. Practical experience has shown that this is a valuable feature with page-printing. With direct transmission all errors appear in the printed message. Also errors are more numerous with direct than with tape transmission, operators being able to do more accurate work on the free keyboard of a keyboard perforator, compared with a direct transmitting cadence keyboard.

The trials were made at 40 words a minute instead of the normal Baudot speed of 30 words a minute, the increased speed being one of the advantages gained by the use of a typewriter keyboard.

The instruments used in the Murray multiplex for tape transmission are shown in Fig. 10.

On the right at A is a keyboard perforator identical with that used in the Murray automatic system. The tape passes from the perforator into an automatic transmitter B. This automatic transmitter is the same as the tape-feeding mechanism of the Murray automatic printer, except that the tape-feeding mechanism is driven in this case by a magnet instead of by a cam. The magnet is operated at regular intervals—four times a second—by the cadence contact on the distributor. This is equivalent to a speed of 40 words a minute.

After running through the automatic transmitter the tape passes on to an automatic tape-winder C. This instrument is of a very simple character and is entirely automatic. Both sides of the tape may be used, so that the cost of the tape is small. The tape also forms a complete "home record" of what the operator has sent. It is neatly wound up without labour cost, and there is no mess of tape on the floor. There is one of these automatic transmitters for each sending operator, so that an extra transmitter attendant is not necessary.

As the automatic transmitter runs steadily at 40 words per minute, it may at times overtake the operator. A starting and stopping lever is therefore provided on the automatic transmitter shown at S. This is arranged with a locking mechanism so that the operator can only start or stop the transmitter at the right moment. There is therefore no danger of interrupting a letter signal in the act of transmission, thereby causing a wrong letter to be transmitted. In this way the operator has complete control over the tape. He can start or stop transmission at will. He can pull back the tape and repeat a message. He can correct errors instantly and invisibly. He has a perfectly free and extremely rapid typewriter keyboard, which he can operate as fast or as slow as he pleases. Only typewriter skill is required, and there is no cadence to be observed.

It is to be noted that it is possible to make a much simpler tape transmitter than that shown in Fig. 10 if the perforations in the tape are arranged crossways, but in that case the tape would not be interchangeable on the Murray multiplex and the Murray automatic systems. At present the tape is identical for the two systems, and it appears desirable to preserve this identity, even at the cost of a little greater complexity in the mechanism of the transmitter.

It will be noticed that tape transmission involves considerable increase in capital cost compared with direct transmission, and it also involves cost for paper tape, but the saving in line and labour is so great that it far outweighs the increased expenditure. Also, if a perforator and tape transmission are not used, then a printer has to be available to enable the operator to see what he is sending out—that is, to supply a "home record." With tape transmission the tape serves as the "home record." The cost of the perforator and transmitter are therefore about balanced by the cost of a printer.

One disadvantage of tape transmission is that a rapid operator may go on perforating until he is several messages ahead of the transmitter. An inquiry may then come through from the other station, and the operator cannot transmit his answer until the messages already perforated have been transmitted. This may take two or three minutes, and it would delay delivery of a message at the other station. An arrangement has accordingly been designed, by throwing over a switch, to convert the keyboard perforator temporarily into a direct transmitter. The tape transmitter is switched out, and the punching magnet of the perforator becomes a cadence magnet. Five contacts are provided on the perforator to be operated directly by the keys. Although direct transmission is not so good as tape transmission, there is no objection to its use for sending a few words of reply to an inquiry. As soon as the reply is transmitted the switch is thrown over again and tape transmission is resumed at the point where it was stopped. The printing mechanism at the other station for recording this temporary direct transmission will be described presently. This arrangement enables direct and instant reply to be made to an inquiry, but it is doubtful whether it would be required in all cases.

Returning to Fig. 8, it will be noticed that there are two contacts on the distributor at station A which are connected direct to the plus and minus poles of the battery. A positive and a negative impulse are therefore sent into the line with each revolution of the contact brushes. This is the governing impulse which controls the speed of the distributor at station B. The method of governing is similar to that employed in the Murray automatic system. The receiving vibrator at station B is identical with the receiving vibrator in the automatic system. It is provided with buffer springs so that the speed of the vibrating reed varies with the variation of the electric current driving the reed. The contacts 6 and 7 on the receiving vibrator, instead of operating a receiving perforator as in the automatic system, energise the two magnets of the phonic wheel-motor driving the contact brushes of the distributor at station B. Varying the speed of the reed will therefore vary the speed of rotation of the distributor contact brushes. Let us assume that the contact brushes at the two stations are revolving at the same speed and that they are in phase with each other. Then, when the brush at station A is on the plus contact of the distributor the brush at station B will be on the positive contact of the distributor at station B. A positive impulse will flow into the line at station A and

will operate the main line relay at station B, closing the relay contact; but there will be no local action in consequence of this at station B, because the plus contact on the distributor is an idle contact with no connection. It will be seen that there is a local battery and a circuit passing through a local relay described as the governing relay. When the two brushes at the two stations reach the two negative contacts on the two distributors the main line relay contact will be opened, and there will be no local action at station B. If now the vibrator at station B is adjusted to run 1 or 2 per cent. faster than the vibrator at station A, then the rotating brush of the distributor at station B will run 1 or 2 per cent. faster than the brush at station A. Hence when the brush at station A is on the plus contact, so that the main line relay contact at station B is closed, the brush of the distributor at station B will have reached the minus contact. The result will be that the local circuit through the governing relay already referred to will be closed, and consequently the governing relay contact will be momentarily opened. This contact is in the same local circuit as the contact that drives the vibrating reed. The opening of the governing relay contact will therefore momentarily reduce the amount of current driving the reed. This will slow down the rate of vibration of the reed and thus reduce the speed of rotation of the distributor brush at station B. In this way the governing impulse from station A will repeat its retarding influence four times a second on the brush at station B. In this way the two brushes at stations A and B are kept not only at the same speed but also in phase, so that when the brush at station A touches successively contacts 1, 2, 3, 4, 5, the brush at station B will also be touching successively contacts 1, 2, 3, 4, 5 on the distributor at station B. Any permutation of signals sent out from the keyboard at station A will therefore be exactly reproduced in the five setting magnets of the printer at station B.

The printer, of which there is one for each channel or transmission of the multiplex, is shown in Figs. 11, 12, 13, 14, and 15; 11 is a side elevation, 12 is a front elevation. 13 is a sectional side elevation, 14 is a plan of the selecting mechanism with the typewriter removed; and 15 is a plan of one of the 5 setting magnets and the comb that it controls. The printer is driven by a small $\frac{1}{18}$-H.P. motor, as shown in Fig. 11. As the printer will print correctly as long as it is driven faster than the distributor, there is no need for synchronism between the printer and distributor, the former being arranged to run anywhere about 20 or 30 per cent. faster than the latter. The Blickensderfer typewriter is employed, and the message forms are fed in automatically from a roll made up in a rather unusual way. The message forms are perforated along each side like a cinematograph film, so as to gear on to sprocket pins on each ends of the typewriter platen. The message forms, in addition to being perforated along the edges, are lightly pasted together so as to overlap and at the same time form a continuous band, which is wound into a roll. The perforations ensure positive column and page-feed, and the overlap of the message forms renders it very easy to pull the messages apart after they are printed. The

printer attendant has merely to pull off the messages one by one as they are finished. This involves an absolute minimum of thought and labour, and he can devote all his attention to checking the messages,

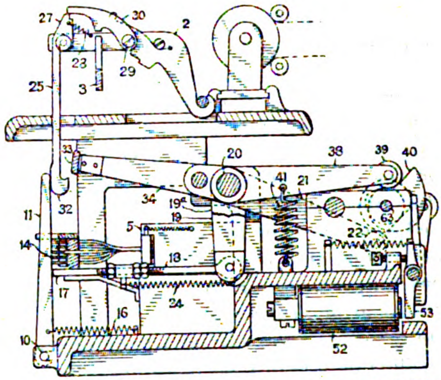


FIG. 13.—Murray Multiplex Printer: Sectional Elevation.

The result is that the receiving operator, when everything is running well, can check up to 150 messages an hour.

In the diagram Fig. 8, at station B there are five small setting

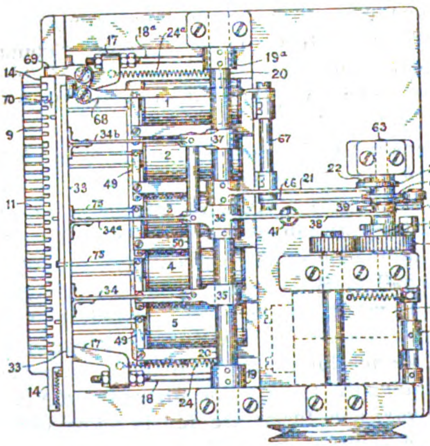


FIG. 14.—Murray Multiplex Printer: Plan View with Typewriter removed.

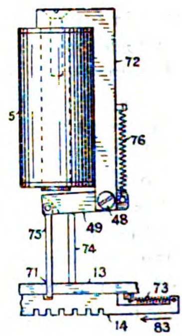


FIG. 15.—Plan of Setting Magnet.

magnets, 1, 2, 3, 4, 5. These are in the printer, and they record the signals transmitted from station A. A plan view of one of these five setting magnets of the printer is shown in Fig. 15: 5 is the magnet coil, 72 is the yoke, and 49 is the armature, pivoted at 48 and retracted

by the spring 76 against the backstop 74. At the free end of the armature there is pivoted a pawl 75, which passes through a slot 71 in the frame of the machine. Resting against this frame are five differentially slotted "combs," or metal strips, lying side by side. One is shown at 14. Each of the five setting magnets controls one of the five combs, the pawl 75 of each magnet engaging in a nick on the inner edge of its corresponding comb. Five springs 73 tend to move each comb $\frac{1}{16}$ in. (1·6 mm.) to the left. When a signal energises one or more of the five setting magnets, the armatures are attracted and the pawls 75 are pulled back out of the way of the combs, which then move suddenly to the left in the direction of the arrow 83, under the action of their springs 73. In this way any given signal is stored up in the printer. Referring to Figs. 13 and 14, the five combs are shown in section at 14 in Fig. 13, and the top comb is seen in plan at 14 in Fig 14.

Pivoted at 10 and crossing the combs at right angles are a series of about 30 latches or crossbars 11. These are held just clear of the combs by the supporting bar 17. Underneath the printer is a printing magnet 52. Referring to the diagram Fig. 8, it will be seen that this printing magnet is energised by the brush arm of the distributor closing a local battery circuit through the printing magnet immediately after the setting magnets have set the combs in some particular permutation representing a particular letter. In practice the printing contact is placed on an inner ring of the distributor, but for the sake of simplicity it is shown in the theoretical diagram in the same ring as the letter-setting contacts. The printing magnet, being energised, attracts its armature 53, which moves out the pawl 54, Fig. 14, thereby tripping a single-revolution clutch. This clutch, on being tripped, connects a constantly running pinion 58 (driven by the $\frac{1}{18}$-H.P. motor) with a cam spindle 63, carrying a battery of three cams. The clutch on being tripped causes the cam spindle to make one complete revolution, the clutch being then thrown out ready for the next printing impulse.

Referring to Figs. 13 and 14, it will be seen that the supporting bar 17 is carried at both ends by two connecting rods 18 and 18*a*, connected to two vertical levers 19 and 19*a*. These levers are pinned to the shaft 20. Pinned to the same shaft is a lever 21 with a cam roller 22. This engages with cam 23, Fig. 14. At the right moment, just after the combs have been set by the setting magnets 1, 2, 3, 4, 5, the cam 23 (set in motion by the printing magnet) allows the lever 21 to rise slightly, thereby pulling in the supporting bar 17 by means of the springs 24 and 24*a*. This allows the crossbars 11 to rest against the combs, the crossbars being pulled inwards by springs 16, Fig. 13. For any given signal only one group of slots will be in alignment across the five combs, and into this group of aligned slots in the combs one particular crossbar drops forward and throws the hook 32 of the hook lever 25 under the universal striking bar 33. These hook levers swing on a pivot on each typewriter key lever 2. The top of the hook lever 27 is prolonged into a catch. On each key lever 2 there is pivoted at 29 a pawl 30. The free end of this pawl

rests normally on top of the catch 27 of the hook levers 25. When any given lever 25 is swung inwards by a crossbar, the pawl 30 drops down at the back of the catch on top of the hook lever 25 and holds the hook in the inward position under the striker bar. The letter signal from the distant station has thus been transferred from the magnets to the combs, from the combs to the crossbars, and from the crossbars to one of the hook levers 25 hanging on a particular key of the typewriter.

The striker bar 33 is carried on the end of three levers 34, 34*a*, 34*b*. These levers are braced into one frame by being pinned to the shaft 50, and they are free to oscillate on the shaft 20 by their hubs 35, 36, 37. From the central hub 36 there extends a lever 38 with the cam roller 39, which is operated by the snail cam 40 on the cam spindle 63. At the right moment this cam raises the lever 38 and depresses the striker bar 33, the striker bar frame oscillating on shaft 20, Fig. 13. The striker bar in its descent engages with the selected hook 32, thereby depressing key lever 2 and printing the corresponding letter on the typewriter. As the key lever 2 descends, the pawl 30 strikes the slotted bar 3 and is thrown out of engagement with the hook lever 25, which is then free to be restored to its normal outward positions by the spring 28 as soon as it is free from the striker bar 33, which is restored to its upper position at the end of each stroke by the spring 41.

The moment a crossbar has thrown a particular hook lever 25 forward into locked position, the supporting bar cam 23, Fig. 14, thrusts the supporting bar 17 forward so as to push out the crossbars, thereby freeing the combs. The moment this happens the combs are restored to their zero position by a third cam 65 on the cam spindle. This cam by means of a chain of levers and shafts, 66, 67, and 68, causes lever 69 at the end of the combs to thrust the combs back in the direction of the arrow 70 to zero position, where they are instantly caught and retained by the magnet armature pawls 75. It will be seen on studying this chain of mechanisms, that the combs can be and are restored to zero position before the depression of hook 32—that is to say, before the printing commences. The result of this is that the setting of the next letter signal by the setting magnets can proceed simultaneously with the printing of the last selected letter. These actions being simultaneous, a more moderate rate of operation is possible for the same speed than would be possible if the actions were successive. This considerably reduces the noise and wear of the mechanism.

The printing does not require description, as any ordinary typewriter action, such as that of the Blickensderfer, answers the purpose.

The line and column feeds of the message form are effected in the same way as in the Murray automatic printer. There is a clutch, which is tripped at the right moment so as to connect with the driving power. This winds up a cord, which pulls the typewriter carriage back to the beginning of the line (line feed), and at the same time turns it up to a new line (column feed). The typewriter carriage

itself throws out the clutch when it reaches the beginning of the new line. This action is extremely simple and rapid, and gives no trouble. The typewriter carriage returns to the beginning of a new line in the time of one letter—that is to say in one quarter of a second. The time consumed in this way is therefore trifling.

The page-feed of the message forms is effected by rotating the typewriter platen through a fixed distance up to the starting-point of a new message. This is effected by a chain of gears and a single revolution clutch. A particular signal for paging up operates one of the crossbars, and this by suitable intermediate mechanisms trips the clutch so as to page up at the right moment. This paging up to a new message form is also very rapid, taking place in the time of two letters, or half a second. This is not counting the paging-up signal. Including the time of this signal, the time of paging up is three-quarters of a second. Page-printing in this machine, therefore, involves only trifling loss of time—on the average not more than 1½ seconds per message, and it saves all the labour and messing and waste of time involved in gumming a tape-printed message on to message forms, the process employed in the case of the Hughes, the Baudot, and other tape-printing telegraphs. Not only does page-printing in the Murray multiplex save time and labour, but the page-printed messages present a good appearance.

One argument used against page-printing by those who have been trained up in the use of tape printers like the Hughes and Baudot, is that as every correction and inquiry involves the use of a message form, there is great waste of message forms. Actual observation during the practical trial by the British Post Office showed that the loss from this source did not exceed 5 per cent. of the message forms used, and even this small loss could be halved by a little care and foresight. Also the writer has designed an arrangement by which inquiries and corrections (R Q's) can be obtained directly printed on a tape, thereby avoiding any waste of message forms, and also avoiding delay. Mention has already been made of the manner in which provision is made at the sending station for direct transmission of R Q's, even in the middle of the transmission of a message, by perforated tape. At the receiving station it is obvious that the R Q must not be printed on the message, the transmission of which has for the moment been interrupted. To get over this difficulty, a small reel of paper tape is provided on the typewriter carriage, and a strip of the tape is stretched along the platen just clear of the printing point. It remains out of the way during the printing of a message. If the operator at the distant station has an R Q to transmit direct, after he has thrown over the necessary switches, as already described, he transmits a special signal (secondary A) which causes the tape on the printer carriage to jump up into the printing position. The printing of the R Q then proceeds direct on the tape, the receiving operator pulling out a fresh portion of tape when necessary. The message form underneath is protected by the tape which receives the printing. When the R Q is finished the

receiving operator pulls down the tape device out of the way, and the printing of the interrupted message in page form can be continued. This arrangement introduces some extra complications, and it is not necessary except in cases where it is desired to save every possible second of time. It is hardly worth while for the sake of saving a few message forms, especially when many R Q's of a brief character and unintelligible to the outside public can be printed at the foot of the page-printed messages, and then struck out with a pencil by the receiving operator.

An important point to be noted about this multiplex printer is that the five setting magnets have very little work to do. They have merely to perform a slight releasing operation. Consequently they can be successfully operated by a very small contact on the distributor. The value of this lies in cases where a considerable number of transmissions (4 to 6) may be required. Under such conditions the contacts on the distributors are necessarily very small.

Receiving Perforator.

With a multiplex printing telegraph system it is a comparatively easy matter to give three towns, A, B, and C, independent and simultaneous communication with each other on one telegraph wire. That is to say, it is not only possible but easy to arrange for A and C to be in direct communication while B is in direct communication with A and with C. More complicated arrangements can be made for simultaneous intercommunication between a larger number of towns, but the increased complexity soon puts a commercial limit on this arrangement. In the case, for instance, of town A transmitting telegrams through town B to various towns C, D, E, F, etc., one message going to one town and another message to another, there would be great difficulty in arranging any system of direct communication on one wire. In such cases there is another solution, namely, recording the messages in town B in the form of perforated paper tape. The messages can then be sent on automatically to any other city desired, and without any great complexity of mechanism. There is no continuous chain of mechanism, the breaking of any one link of which will cause the whole arrangement to collapse.

In the Murray automatic system all the received messages are first recorded at a high speed as perforations in paper tape, and from this perforated tape the messages are afterwards printed automatically. In the Murray multiplex a different kind of receiving perforator is provided. This instrument is shown in Fig. 16. It is essentially a Murray keyboard perforator tilted up on end and with the keys omitted. In place of the keys there are five small magnets which do the work of the keys—that is to say, they control selectively five small steel rods, which determine the holes to be punched in the paper tape. These five magnets correspond exactly with the five setting magnets of the multiplex printer (see Fig. 8). Each of these five setting magnets

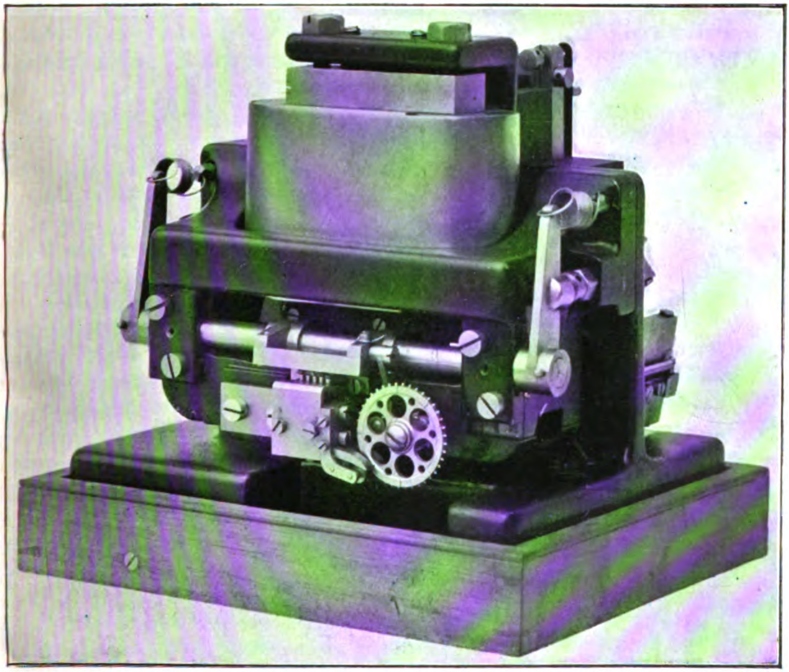


Fig. 16.—Murray Multiplex Receiving Perforator.

of the receiving perforator are placed in series with the corresponding one of the five setting magnets of tho printer. The punching magnet of the receiving perforator is operated by the same impulse as that operating the printing magnet (Fig. 8) of the printer. On the printer there is provided a switch to throw the receiving perforator into or out of action by means of a signal from the distant station. If the sending operator at the distant station A has a message which requires to be transmitted at station B to, say, station F, he transmits a special signal which throws over the switch in the printer at station B. This puts the receiving perforator in action. The message is then recorded as perforations in tape by the receiving perforator at the same time as it is being printed in page form by the printer. At the end of every message the page signal, in addition to turning up a fresh telegraph form, automatically cuts out the receiving perforator. Consequently only messages requiring retransmission are perforated, and the sending operator has control over this operation at the distant station. As there is a printed message produced at the same time as the perforated tape, a glance at the printed message will show whether it has been correctly received. If it has been received correctly, then it can be automatically retransmitted to its destination by means of the perforated tape. If the message has not been accurately received, it can be corrected and sent in the ordinary way by manual instead of automatic retransmission. That is to say, it can be perforated again correctly on a keyboard perforator. In this respect the receiving perforator and tape retransmission present a decided advantage over the methods of direct communication between several towns, because any breakdown of the receiving perforator leaves all the ordinary working mechanism intact, and transmission can proceed in the ordinary way. This multiplex receiving perforator offers two main advantages in addition to that just mentioned, namely, (1) the message is printed and also perforated simultaneously, (2) only messages requiring retransmission are perforated. The others are printed only.

Preparation of Message Forms.

It is obvious that in a page-printing telegraph printing direct from the received signals, it is necessary to have some positive and automatic method of throwing out the finished message and feeding up a new message form to the right printing point. This may be done in two ways: (1) By feeding from a pile of cut forms, or (2) by means of a continuous roll of message forms. During recent years a number of devices have been perfected for feeding in separate sheets of paper one after another automatically into printing machines. There are undeniable advantages in this cut form plan, but the cross motion of the typewriter carriage presents serious obstacles to its employment in printing telegraphs. There is also the consideration that occasionally a message form may fail to feed into the printer, and the corresponding message would not

be recorded. This would entail delay and repetition, and in some cases confusion and possible loss of a message or delivery of a message twice over. The continuous roll feed is free from these objections, but it entails preparation of some kind beforehand. Some slit or perforation has to be made in the paper band at the top of each message form to ensure positive feeding in of the forms to the right printing point. The messages have also to be cut apart with a pair of scissors or by other means. The arrangement adopted in the Murray multiplex may be described as a compromise between the two methods. Cut forms are employed, but they are lightly tacked together with dextrin so as to overlap. They are also perforated along their sides like cinematograph films, so as to ensure positive feeding up to the point for starting the message. This arrangement works well, and it has the advantage that the receiving operator has merely to pull off the messages as they are finished. There is an absolute minimum of trouble in this respect. For the preparation of the message rolls beforehand, a punching tool is employed, which perforates 8 to 10 messages simultaneously. This is a quick and simple operation and a large number of messages can be perforated at trifling cost. Pasting the messages together into continuous rolls also presents no difficulties. The work can be done by a boy quite rapidly by hand on a table without any mechanism; and in cases where large quantities are needed, a machine has been made to turn out the rolls quickly and cheaply.

Time Stamp and Press Copier.

In the case of printing telegraphs handling a large number of messages, a time stamp saves a good deal of labour, and such an instrument is of special value in the case of a system like the Murray multiplex, where there is a possibility of one receiving operator attending to two printers, each producing 80 or more messages an hour. There is now at least one good time stamp on the market, and it is probable that such instruments will come into extensive use in connection with printing telegraphs during the next ten years. The time stamp will print on the telegrams instantly the date and time of reception, the number of the circuit, and any other particulars, including a number or other mark identifying the operator receiving and checking the messages. Actual experience has shown that an operator can easily check 120 messages an hour, and it is possible to check 150 an hour. With the aid of a time stamp it is believed that it would be easy to check 150 to 160 messages an hour. That is to say, except during times of great pressure, one operator would be able to attend to two multiplex printers, each turning out about 80 messages an hour.

There are a number of excellent wet-press copiers now in commercial use, and in time wet-press copying will overcome the trouble about keeping a copy for record of telegrams issued to the public.

With a good multiplex printing telegraph such as that just described, and with a time stamp and press copying, the labour cost of telegraphy will be reduced to about the lowest point possible.

Results with Murray Multiplex.

It is too early yet to say positively what results can be obtained with the new Murray multiplex system, especially as there are still a number of detail improvements to be made. A complete installation has only recently been completed for the British Post Office, and is now being installed between London and Manchester. Prior to this, an experimental set, giving one transmission only, was made by the British Post Office, and tried for about six months between London and Birmingham. The results were surprisingly good. The sending operators were two girls without previous experience on typewriter keyboards, and yet within one month they were each punching from 40 to 45 messages an hour. After about three months' practice each of these two girls succeeded in perforating 100 messages in one hour. Excluding several days when there were interruptions and breakdowns due to imperfections in the experimental apparatus, and excluding several days when traffic was light, the average number of messages on the one channel or transmission of the multiplex was over 80 per hour. On several days during busy hours the average exceeded 100 messages an hour. On one day, for instance, during three consecutive hours from 10 a.m. to 1 p.m., the numbers were 104, 126, and 102 messages per hour.

APPENDIX.

Since writing the foregoing paper I have been favoured by the Direction General of Russian Posts and Telegraphs with an official letter giving some interesting information in regard to the employment of the Murray automatic system on the telegraph line between St. Petersburg and Omsk. The letter, translated into English, is as follows:—

"In reply to your letter of 28th February, 1911, concerning the adaptation of the Murray apparatus to the telegraph line Omsk—St. Petersburg, the Direction General has the honour to inform you that this line has a length of 3,557 kilometres [2,224 miles], and has three repeating stations, namely, at Riazan, Samara, and Tcheliabinsk, arranged at the following distances: St. Petersburg—Riazan 865 kilometres [541 miles], Riazan—Samara 872 kilometres [545 miles], Samara—Tcheliabinsk 1,004 kilometres [628 miles], Tcheliabinsk—Omsk 816 kilometres [510 miles].

"The line is of iron wire and measures six millimetres [0·236 inch] in diameter.

"The line is worked duplex in an entirely satisfactory manner, and it is not necessary to revert to simplex except in the case of very bad atmospheric conditions.

"The regular operation of the Murray automatic apparatus on the St. Petersburg—Omsk line was inaugurated on the 19th April, 1908.

"The speed of transmission in each direction with the Murray automatic system, working duplex, is from 56 to 60 words a minute.

"The speed of transmission by the Wheatstone system on the same line did not attain more than 30 words a minute (six feet of tape), rarely 35 words (seven feet of tape), and under the very best conditions, and then only during very short periods of time, 40 words a minute (eight feet of tape).

"The foregoing practical results show that the effective speed of transmission on this line is far below the theoretical speed obtained by calculation. This difference appears to be due not only to atmospheric conditions, but also to the influence of the auto-induction of the line, and, above all, to the influence of the reciprocal induction of neighbouring wires running parallel with this line over long distances."

The words in parenthesis ( ) occur in the letter, but the words in brackets [ ] have been inserted by me. It will be seen from the facts given in the letter that the Murray automatic system has nearly doubled the carrying capacity of this St. Petersburg—Omsk line compared with the Wheatstone, which was formerly employed on it. Satisfactory duplex working on such a long line is remarkable, and should be a matter of encouragement to other Administrations with very long lines. It will be seen that the Murray automatic system has been in successful commercial use on this line for three years. The speeds are given in words per minute. These speeds are reckoned on the basis of five letters and a space equal to a letter per word. That is to say, they correspond to six typewriter letters or their equivalent space. The speeds of 56 to 60 words a minute are therefore equivalent to 336 to 360 letters per minute. The Wheatstone speeds are on the same basis.

Discussion.

Major O'Meara.

Major W. A. J. O'Meara: Some of us remember the paper on this subject which Mr. Murray read some five or six years ago. He has now told us of the advances which he has made since that time. I sincerely congratulate him on having turned his attention to the Baudot principle. Many inventors of printing telegraphs have an idea that the ordinary message consists of about one thousand words, and consequently they turn their attention, in developing systems, to dealing with these long messages. Mr. Murray has, fortunately, had some practical experience of the working of British telegraphs. Therefore what Mr. Murray tells us is really based on practical experience, and he realises that there is a more profitable field for invention if the problem is dealt with from the point of view of the actual messages

which form the great bulk of those which have to be transmitted in this country. I entirely agree with him that the telephone will, in the future, be a feeder for the telegraph system. I think this problem of the telegraphs has to be very carefully considered, since we may come to a state of affairs when we shall only have long-distance telegraphs. In that case, we should have to take care of the line (which is the costly part of the system) and we should have to develop a system which will make the best use of the "line-time" in connection with messages the majority of which average eighteen words. Mr. Murray has shown us how we can make very much better use of the "line-time" by the printing telegraph as now developed by him than is possible with other systems. Major O'Meara.

When in America recently I had an opportunity of discussing this subject with experts of that country. Some people have an idea that the use of a transmitting tape involves waste. If, however, they give the matter careful consideration, I think they may alter their opinion. If a telegraph operator, especially with the page-printing system, makes a mistake, one of two things has to be done: either the message has to be rejected at the receiving end, or a correction has to be made. Now it is felt that a correction which appears on the blank form which goes to the public is a mistake, because, unfortunately the public are rather suspicious; and if they see a correction they suspect cooking. A transmitting tape at least reduces the liability to errors. In America, I observed that the whole message was rejected at the receiving station if a mistake were observed, and that the message was re-transmitted. Such procedure certainly involves waste of the "line-time." I am inclined to think that in connection with all these high-speed systems the tape is the proper thing, especially if that tape can be inspected and, if necessary, rejected before it is put through the transmitter. By that means, I think, the greatest use will have been made of the "line-time."

Mr. C. HIGGINS: I wish, first, to congratulate Mr. Murray upon the improvements which he has effected in his printing telegraph machine. In regard to mistakes arising from confusion of the shillings and pence separated by a diagonal line with the numerator and denominator of fractions separated by a diagonal line, we do not experience any trouble in this connection, as is shown in the example of our Stock Exchange tape (Fig. A); the shillings and pence are separated by a diagonal line, and the numerator and denominator of the fraction by a horizontal line, which effectually prevents mistakes. It must be remembered that there are two distinct spheres of activity into which the printing telegraph can enter, and in which the requirements are entirely different, viz.: first, the transmission of messages, and secondly, the distribution of news. This latter is the one branch of telegraphy which demands as essential an apparatus recording in Roman characters. In regard to Major O'Meara's suggestion that the telephone will supplant the telegraph for short-distance work, surely he does not include in that category the "Distribution of News." Mr. Higgins.

Mr. Higgins. Consider the case of a certain service of ours where some 500 subscribers require some item of news instantaneously. We cannot picture 500 telephones and their attendants being brought in to supplant our apparatus, which effects the necessary transmission with celerity and accuracy, and provides a record from one transmitter operated by one operator, who could transmit equally well to 1,000 subscribers, and that upon apparatus requiring no skilled attention.

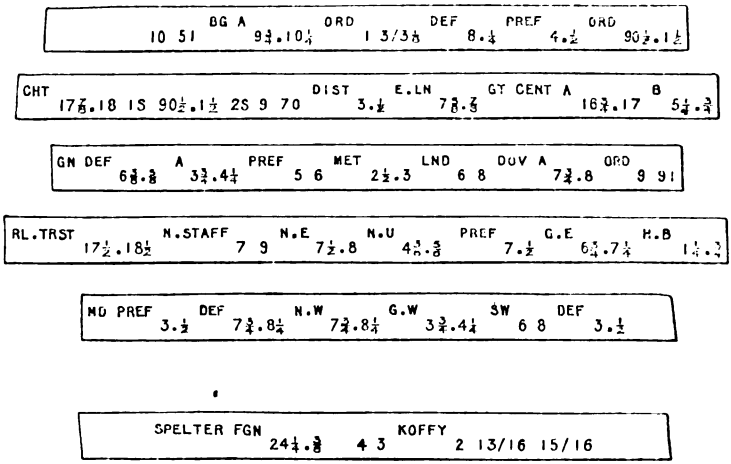


Fig. A.

Naturally, we sacrifice speed a little to effect such multiplicity of transmission, and the specimen of tape shown represents a speed of 50 words per minute from the automatic transmitter (6 letters per word); we cannot afford to utilise intricate apparatus requiring skilled attention at every receiver. We utilise instruments which must be relied upon to work when placed in a subscriber's office, and simplicity is the keynote of this class of apparatus. The work of the Exchange Telegraph Company is greatly increasing, and last year the aggregate number of words reached 650,000,000 on the instruments under our own control, and a great number on Exchange Telegraph Company's instruments employed to work the services of other news agencies.

Mr. Mansbridge. Mr. G. F. Mansbridge: In regard to the matter of the telephone assisting the telegraph, or the one acting as handmaiden to the other, I quite agree with Mr. Murray and Major O'Meara that there must be some assistance from the one to the other, but as to the extent of this I should like to utter a word of warning. I think that the telephone can never do a great deal in the way of feeding the telegraph, because the principle on which messages are sent over a telephone line is fundamentally different from that employed with the telegraph. Mr.

Murray has given one indication in his paper of that difference when he refers to the difficulty of telegraphing Chinese messages. The difficulty arises from the fact that Chinese writing consists of ideographs, and that ideographs, other than those comprised in the Morse alphabet, cannot readily be transmitted by alphabetical signals. In the case of the telegraph the system of transmission rests on the same foundation as our system of writing, *i.e.*, the message is transmitted by spelling out the words letter by letter. In telephonic transmission, however, complete words—*i.e.*, practically ideographs—are sent through in bulk, and the moment it becomes necessary to transmit an unfamiliar ideograph or word, the system breaks down and recourse has to be had to the telegraphic method of spelling. But even this does not entirely get over the difficulty inasmuch as the telephone is but an inefficient device for transmitting with certainty isolated and unconnected letters—contrasting most unfavourably with the telegraph in this respect—and so in such cases resort has to be made to the quaintly primitive device of transmitting letters by means of words. For example, to transmit the commercial abbreviation "cif" over the telephone it might be necessary, on the score of accuracy, for the sending operator to say "cif : *c* for cat, *i* for ink, *f* for father." To take an illustration from the paper, on page 493 the author gives a code message. I can fancy the dismay of any operator having to receive that code telegram over the telephone. Although that message is perhaps an exceptional case, yet, if we take a hundred commercial telegrams, we should find very many phrases or names which offer much the same difficulty. It comes to this, therefore, that while the telephone may be useful for the message of the type "I shall not be home to-night," I do not think it will be of any great use for ordinary commercial telegrams. The situation as I view it may be summed up by saying that while the telephone is a highly efficient method of communication between principal and principal, its efficiency for commercial purposes—in which accuracy must have pride of place—drops enormously as soon as an intermediary has to be employed. Mr. Murray has paid a compliment to the Baudot system by employing that code for some of his apparatus, and I was therefore the more surprised to find Baudot working referred to as monotonous. The only basis which I can see for the suggestion is that sending on a Baudot keyboard involves a minimum of mental and physical strain ; such "monotony" surely tends to the well-being of the operators. Mr. Mansbridge.

Mr. F. RYAN : There is only one point to which I should like to draw attention, and that is the use of the keyboard perforator. I should like to know what the experience of others has been with this instrument. The experience of the Cable Company, with which I am connected, has not been quite so fortunate as the author's. We issued a certain number of these instruments about two years ago, and the reports from all stations were that there was a good deal of strain in the typing of code messages, and the percentage of errors was certainly increased. We have recalled those keyboard perforators, and have Mr. Ryan.

Mr. Ryan. converted them for working with a 12-key instead of the usual 52-key board. We do not quite know what the results will be.

Mr. Evershed. Mr. S. EVERSHED: I notice that to all telegraphists the counting of the words in a telegram seems to be a regular nightmare. I suggest that the sender of a telegram should be forced to count the words, or, rather the letters, in his telegram. This can be done in such a way that he would not be aware of the fact that he was doing anything of the sort. All that is necessary is to have the telegraph form ruled in horizontal lines which are divided by vertical strokes into compartments, each compartment being intended to contain a single letter or digit. At regular intervals along the lines the cost in pence would be printed, so that neither counting of words nor reckoning of cost would be required. Writing in compartments is not difficult, and it has the great advantage that the writer is compelled to adopt a legible and rather copybook hand. A further advantage of compartment writing is that since the cost of the telegram is based upon the number of letters the present difficulty with regard to what the author calls Siamese-twin words disappears altogether. My scheme sounds a little complicated and possibly a little ludicrous, but is not the less fitted for a Government Department for all that.

Mr. Stubbs. Mr. A. J. STUBBS: I am interested to see that Mr. Murray has arranged a device for temporarily changing the keyboard perforator into a transmitter. This was done by Carpentier, of Paris, two or three years ago for the Baudot, but I had no idea that Mr. Murray had adapted it to the Murray Multiplex. Perhaps a word of emphasis is worth giving in connection with the latest instrument that he refers to—the arrangement for receiving simultaneously a printed page and a perforated slip. I anticipate that that would be an extremely useful device in the circumstances which the author describes. Supplementing Major O'Meara's remarks with regard to the slip *versus* page printing, I think Mr. Murray rather anticipates that criticism in regard to the faults made by the operator who is preparing the slip; but no device can anticipate the faults which are introduced by line faults in transmission. So that (no matter how carefully a slip may be prepared) with a type-printing device there will always be errors introduced by momentary faults on the line, and it is these which make page printing apt to appear defective. I have no doubt that it is evident to nearly all engineers that the point of slip printing in this connection is that all defects can be easily cut out by the operator, during the process of very rapidly mounting-up the slip as it is received.

Mr. Judd. Mr. W. JUDD: In our cable system we have had very little occasion to use apparatus of the sort described by the author, and I do not suppose that this particular system, or any one exactly similar to it, will be adopted on long cables. But in any system that we do adopt, I fancy we shall insist on retaining the old Morse alphabet or the variation of it, the cable code alphabet. Supposing the new perforator or printing apparatus breaks down, we want to have the power of reverting to our old and well-tried recorder system, without a moment's

delay, so that the same automatic tape punched out at the other end of the line shall be at once available for use in connection with our standard apparatus. We should feel lost if we had to adopt another language, so to speak, and became in a way bilingual at a moment's notice. It would be troublesome, to say the least of it. I was very interested to read Mr. Murray's remarks on the traffic aspects of the system. There are very great difficulties introduced in all these matters, because in a printing telegraph, particularly in a page printer, considerable risk is run of having mutilations and errors introduced into the page, which are difficult to correct. The tape printing is, no doubt, distinctly the best method at the present time at any rate, on account of the ease with which corrections can be made. Even then, the difficulties are not entirely overcome. There is the trouble, with the slip system, of gumming it on a delivery form, of getting the wet copy, and of the chances of the gum oozing out from the slip, thereby causing the flimsies to stick together. Still, no doubt, these difficulties will be overcome. With regard to the tape being perforated at the receiving end ready for onward transmission, there are a good many difficulties from the traffic point of view. We are hoping, before very long, to adopt such a machine for use on cables. We have been using one designed by Mr. S. G. Brown many years ago in connection with his relay. That worked up to a certain point, and we now hope to get one which will come into general use. It is in experimental use at present. The mechanical difficulties are far less than the traffic difficulties. All messages, at any rate on cables, carry a running number. These messages take a new number at each transmission, and it is obviously impossible to perforate a new number on the received slip. A way out of that difficulty has to be found, and the way we are hoping to get over it is to use one running set of numbers, say, between London and Adelaide, another between London and Bombay, and so on. These details may not be of much interest, and I only mention them to show that new methods bring a lot of difficulties in their train. No doubt surprise is felt that new apparatus is not at once adopted. It does not seem to be understood that new methods bring a lot of problems with them which have to be solved before they can be used commercially. Mr. Judd.

Mr. J. HUME BELL: The author refers to the bad handwriting of the general public as being partly responsible for the reduced speed of working on keyboard perforators. With this statement I agree. The full advantage of increased output which might reasonably be expected from the use of keyboard instruments will not be secured until an improvement in handwriting, especially of business messages, is insisted upon. Keyboard operators, who can work at 60 to 80 words per minute from typed or printed matter, are compelled to adopt a very much slower speed when dealing with badly written telegrams. I am sorry Mr. Murray has stuck to page printing in preference to printing on slip. Page printing involves the use of more complicated apparatus and necessitates the adoption of one type of message form. Against Mr. Bell.

Mr. Bell. the economy in operator labour must be set additional mechanical attention. I should like to point out a serious disadvantage which must result if the present coloured message forms are given up. There are in use, in the Central Telegraph Office, five kinds of forms, each of a different colour. This colour scheme enables the boys engaged in collecting the messages from the instrument table racks to effect a primary sorting whilst carrying them to the distributing tables. This materially reduces the time taken in handling the messages within the office. With a slip-printing telegraph instrument the slip can be gummed on the existing forms, so that the present method of dealing with messages need not be altered. Mr. Murray refers to receiving perforators for re-transmission purposes. An extension of their use in this direction is desirable. Some two or three years ago a Creed receiving perforator was in use in the Special Section of the Central Telegraph Office. Prior to its installation it was customary for a certain news message of 1,000 or 1,200 words in length, which was received from Newmarket daily, to be recorded on Morse slip, written up by hand, re-perforated by hand, and then transmitted to a provincial office. These operations took about an hour. When the message was received on a Creed receiving perforator the time taken was reduced to ten minutes, and operator labour equal to about five man-hours saved. I agree with Mr. Murray that, provided capable operators are in control of the apparatus, the further introduction of printing telegraphs will tend to reduce the number of errors. Some time ago I saw in a German journal the following particulars as to the number of errors per hundred messages :—

Morse slip writing	0·019
Morse sounder	0·011
Hughes printer	0·004

Mr. Noble. Mr. W. NOBLE: Major O'Meara has referred to the fact that the author was able to deal with this question of printing telegrams better because of the knowledge of practical working gained in the British Post Office. I always thought, after coming in contact with Mr. Murray in the Post Office, that it would have been in the interests of the Department, as well as of Mr. Murray, if he had at the outset spent six months continuously in the telegraph galleries, there to see the actual working of the different systems, and the operating as it is in actual practice. There is no doubt Mr. Murray would have foreseen and avoided many of the difficulties he was up against at a later date. The author, on page 454, refers to the Baudot and Hughes as being used for inland work in France and Germany, and for Continental work in this country. I think it would be interesting for the members to know that the British Post Office is extending the use of these instruments for inland work, and has recently installed a Baudot quadruple duplex between London and Birmingham. The result is so satisfactory that no doubt the use of the Baudot will be extended in this country when more apparatus is available. With regard to the Hughes, a few years ago

Mr. Noble.

there were no Hughes duplexes for inland work; but, at the present time, there are twelve working between London and Manchester, Liverpool and Glasgow; so we are following the lead of the Continental countries in this respect. On page 460 the author says that the printing telegraph is absolutely a commercial question. I hope Mr. Murray comes to this opinion after his experience with the British Post Office, because, if so, he will no doubt agree with me that it will be unnecessary to have a special telegraph authority to deal with the telegraphs. Mr Murray's automatic system has not been referred to during the discussion, and, as he says a good deal about it in his paper, it may not be out of place for me to make a few remarks upon it. On page 460 Mr. Murray says the three main points dealing with printing telegraphs are: first, a saving of labour; second, a saving of line; and, third, a saving of time. I do not know whether it was the introduction of Mr. Murray's system into the British Post Office that caused the Post Office to return to its old love, the Wheatstone, but, in any case, trials have been made with what is known as "Systematic" Wheatstone, and the results have been highly satisfactory. As most of the members will, no doubt, be aware, until recently the method of Wheatstone working involved the use of the hand perforator, and, at the receiving end, the messages were written up by hand. Now the Department is adopting keyboard perforators, which give a much higher speed than the ordinary hand perforator, and at the receiving end it is now adopting the practice of the cable companies, namely, instead of writing up the slip, to paste it on telegraph forms. The great advantage of this will be evident when I state that in many of the large centres the percentage of what are known as "X" messages is about 70 to 75. Ordinarily these messages come off the Wheatstone, are written by hand, and then transmitted to the next station. Nowadays, in the Systematic Wheatstone, these messages are pasted in the Morse slip, taken to the instruments, and forwarded by the operators from the Morse slip. My point is this, that it is much cheaper to use the Wheatstone in this way for the whole 100 per cent. of messages, since approximately 70 to 75 per cent. of them have to be re-transmitted, and are equally well re-transmitted from the Morse code, because this is less costly, and quite as reliable as printing telegrams. The "S" messages can be typed from the Morse slip. Furthermore, I should like to point out that the Wheatstone is largely used by the British Post Office for news work, and, therefore, there is always Wheatstone apparatus to spare, so that if one set breaks down we can transfer to another. With a special type-printing telegraph it is always necessary to have a duplicate set available, and this is costly. In a paper which was given by Major O'Meara at the first International Telegraph Conference at Budapest, it was mentioned that in a recent trial the saving of line and labour resulted in favour of the Wheatstone, and as regards time the two systems gave equal results. I should like to refer to the new apparatus. I like the new instrument, and if it fulfils all that is expected of it—and I hope it will—it will be a valuable addition to the

Mr. Noble. apparatus in the British Post Office. There is, however, one thing I rather doubt, namely, whether Mr. Murray will get a continuous forty words per minute on this instrument. The Baudot gets about thirty on an average, and I shall be very much surprised if this new instrument goes much above that figure.

Before concluding, I should like to refer to one or two rather Utopian ideas of Mr. Murray. For example, he says on page 458 the system of the future will, no doubt, be for a merchant to call up on his telephone and ask to be put through to the telegraph operator in order that he may dictate his telegram. I think that is a condition we are never likely to meet with, because a merchant, in the first place, will be sure to have his telegram written out or typed before he sends it over the telephone, and I do not think the merchant will spend his valuable time in re-dictating that message, especially as we know that the sending of telegrams over the telephone is a slow process. That it is impracticable in London will be gathered from the fact that at present at most of the offices in inner London thousands of messages a day are sent by pneumatic tube. In one case from one office 2,500 messages are sent into the Central Telegraph Office. The sending of this number of telegrams over the telephone cannot be imagined by practical officers. The aggregate delay would be serious and the number of telephone lines required would be great. I should like the members of this serious Institution not to take too literally the telegraphic blunders which Mr. Murray has put into his paper. The one about the blistering of pigs is well known. It is rather too much to believe that the intelligent and usually well-educated Irish operator would really send out such a telegram. The same applies to the joke about the mistake of "Almighty" for "Admiralty."

Mr. Harrison. Mr. H. H. HARRISON (*communicated*): I am not sure that there is not also a field of application for printing telegraphs to railway work. Telegraph traffic on a railway nearly all relates to the movement and disposition of rolling stock. On a large railway system with a great variety of vehicles, code words are used to denote the different classes. The messages usually start on their journey as "phonograms," and are very slowly handled. While it is not conceivable that type-printing would be suitable for handling long-distance railway telegraph traffic, there might be some advantage in using a simple type of printing telegraph between the various local offices radiating from an important telegraph office, and which are at present inefficiently served by telephones. There is no reason why the telephone should not still be used for conversational purposes, the printer being superimposed on the telephone loop. For military purposes, also, there seems to be a field for the employment of printing telegraphy. I am sorry that Mr. Murray condemns Esperanto. I should have thought that an International language would have helped the printing telegraph inventor. I can confirm what Mr. Murray says as to the mechanical or automatic way in which telegraph operators can work. When I was in the Central Telegraph Office about twenty-four years ago I used to be able

Mr. Harrison.

to send a message with my right, and sign and time the messages simultaneously with the left hand, and this was not an uncommon accomplishment. The adoption of the Lacour wheel to driving a Baudot distributor is, in my opinion, a step in the right direction. It simplifies Baudot gear considerably, and should give much steadier running. The difference between direct and tape transmission is rather surprising when one reflects that with a keyboard transmitter the cadencing is much easier. It would be interesting if Mr. Murray would give his reasons for using the Blickensderfer printing mechanism on the multiplex printer only when the same mechanism is used on the high-speed automatic Buckingham-Barclay printer. The paper raises the question, not yet definitely answered, as to the relative advantages of page and tape printers. The page printer must always be more complicated than the tape instrument. It has a larger number of parts, has additional functions, and is therefore subjected to much greater wear and tear. It is also more costly to install. Maintenance costs for a given output will largely settle the matter. There are, however, other aspects than mere cost, installation, or running. The blank is ejected from the page printer ready for issue to the public, while with the tape printer an additional process is necessary.

Mr. Murray.

Mr. DONALD MURRAY (*in reply*): The discussion that has taken place shows that not the least of the practical difficulties in the way of printing telegraphy is the conservative tendency of officials and the public. Fortunately there is a famous old engineer named Anno Domini, who is on the side of progress, and in due course his decisions will settle all controversy.

What Major O'Meara says about the advantages of perforated tape transmission of messages confirms my experience, and I am glad, also, that Major O'Meara agrees with me in thinking that in future there will be increasingly close co-operation between the telegraph and telephone. Some of the other speakers seemed to be doubtful on that point. Mr. Mansbridge, for instance, mentions the trouble in telephoning difficult words and figures which are so numerous in commercial messages. The difficulty certainly exists, but telegrams are telephoned every day, and it is too late now to maintain that the telephone cannot transmit anything that can be telegraphed, provided always that the telephone line is sufficiently short to give clear speaking. In saying that the Baudot direct transmission is monotonous, I was simply repeating what Baudot operators have told me. Actual trials have proved beyond question that a free typewriter keyboard is much easier and less monotonous than direct transmission with a cadence. Experience has taught me to agree with practically all that Mr. Judd says about printing telegraphs in connection with ocean cables. The conditions are very severe, and it seems to be a necessity to retain the Morse or cable code alphabet. The point mentioned by Mr. Judd about numbering messages on cables is an interesting illustration of the practical difficulties in the path of telegraph inventors and innovators.

Mr. Murray. In regard to Mr. Ryan's remarks about the use of typewriter keyboard perforators by the Eastern Telegraph Company, the conditions in the cable service are undoubtedly very unfavourable for typewriter keyboard instruments. The difficulty about code words and figures can be overcome by proper training; but with cable stations scattered all over the world, it would appear to be almost impossible to give the training required, except at considerable expense extending over several years, and in any case the advantage to be gained is not very large. Mr. Higgins's automatic tape transmission for stock and news tickers is a very interesting development, and is directly in accordance with the arguments and experience in favour of automatic transmission in other branches of telegraph work. In reply to Mr. Harrison, the use of the typebar is necessary for high-speeds, because it is much more rapid than any typewheel, and its use at a high speed involves much less strain.

Several speakers referred to the question of tape-printing *versus* page-printing, and two arguments were advanced in favour of tape-printing. (1) Mr. Stubbs pointed out the advantage of being able to cut out all errors from the printed tape, so that no corrections appeared in the message as delivered. (2) Mr. Hume Bell pointed out the advantage of being able to paste the printed tape on to various kinds and colours of message forms. Dealing first with the argument mentioned by Mr. Stubbs, I may point out that if all errors are to be eliminated by cutting them out of the tape-printed messages, much delay will be involved. For instance, take the telegram: "Arriving tomorrwo at 4 p.m." This contains a very frequent error, namely, a transposition of letters. Surely it is not necessary to ask the sending station to re-telegraph the word "tomorrow" in order that it may appear in the message free from correction. Similarly, we have such mistakes as "Londom" for "London," and thousands of other obvious errors of the same kind. Are we to waste time and labour, and delay delivery of messages, for such trifles as these, when a stroke of the pen can put them right? Tape-printing certainly does not give messages free from correction, except at the expense of delay and waste of labour. Page-printing with invisible correction of errors before transmission meets the objection about errors as far as practical requirements demand, and the saving of time and labour by page-printing is very considerable. Actual experience at the British Post Office shows that an operator can paste up on the average about 200 British tape-printed messages on to telegraph forms in one hour, provided he does nothing else. If he also checks the messages, his output is much reduced. With a completely automatic page-printing telegraph like the Murray multiplex, the whole of this work is done by the machine. Taking a circuit exchanging 2,000 messages a day on a page-printing telegraph, the calculated saving of labour would therefore amount to 10 man-hours per day. The actual saving for various practical reasons is probably considerably more than this, and there is ground for believing that the saving of labour on such

Mr. Murray.

a circuit with page-printing will amount to about one operator at each end of the line. The saving of time is also of importance. Pasting up 200 messages an hour means a delay of 18 seconds per message. The Murray multiplex printer does this work in less than 2 seconds. The saving of time by page-printing therefore averages not less than a quarter of a minute per message. With a page-printing telegraph, also, the messages are ready for checking the moment they are printed and paged up. With tape-printing, at least several words must intervene between the printing and the pasting-up. That represents several more seconds of time lost compared with page-printing.

In regard to the second point, raised by Mr. Hume Bell, namely, the convenience of pasting printed tape on to various kinds and colours of message forms, that difficulty is met with ease by the use of rubber stamps with different coloured ink-pads. There is no more difficulty for the operator to select the proper rubber stamp than to select the proper coloured message form, and there is the very considerable advantage of uniformity—a single message form throughout the service. As Mr. Bell points out, the percentage of errors in telegrams is quite small, but I think the figures he quotes refer to errors complained about by the public, that is to say, errors that passed unnoticed by the checker. I believe errors detected and corrected vary from about 1 per cent. under favourable conditions to about 10 per cent. in unfavourable conditions. Mr. Bell's figures, however, illustrate quite well the superior accuracy of printing telegraphs compared with manual telegraphy.

Mr. Noble referred to the introduction of the Hughes on inland circuits in Great Britain; but the introduction of the Hughes on busy circuits seems to me to be a retrograde step. The Hughes type-printer in an improved American form was once largely employed in America, but it is a good many years since its use was abolished by the Western Union Company. Instead of the Hughes, the Western Union has now about 60 circuits equipped with the Buckingham-Barclay perforated-tape-transmission page-printing telegraph. These Hughes machines on busy inland circuits in Great Britain will certainly be superseded before long either by the Baudot or the new Murray multiplex or automatic, or by some other of the more efficient modern printing telegraphs. Mr. Noble also referred to the newly established Baudot circuit between London and Birmingham, the solitary inland Baudot circuit in Great Britain. That undoubtedly is a step in the right direction, and it smooths the path for the introduction of the Murray multiplex, which may be described as a modernised Baudot. But the establishment of the first Baudot circuit in Great Britain in the year 1910 does not appear to me to be a sign of much enterprise on the part of the British Post Office. The Baudot system has been in successful use in France for 30 years, and there are now several hundred Baudot circuits in France, Italy, and neighbouring Continental countries. Russia has about 50 Baudot circuits. India and Brazil have had several in use for some years. Germany has had several Murray automatic circuits in daily commercial use for some years, and Great Britain has not one, although

Mr. Murray. there are three or four British circuits on which it could be applied with advantage. In Russia they have been working two very successful Murray automatic circuits for several years, one of them a truly remarkable long-distance circuit, and yet British telegraph engineers cannot show one Murray automatic circuit at work. It is true the British Post Office is getting a new installation of the Murray automatic for London to Dublin, but that is the total result of eleven years' dabbling with the subject.

The chorus of self-congratulation that has arisen recently from some British telegraph officials about "systematic" Wheatstone working, is certainly surprising to onlookers. The obvious comment is that if Wheatstone working in Great Britain has not been "systematic" until recently, then that fact is not one to be proud of. "Systematic" Wheatstone is just common-sense Wheatstone. The cable companies have used the same plan for a long time past, and I saw "systematic" Wheatstone, just as Mr. Noble describes it, being worked on a considerable scale in St. Petersburg and Moscow five years ago. A large number of typewriters were also in use for typing up the Wheatstone tape messages. At that time I do not think there was a solitary typewriter in use for telegraph purposes in all Great Britain. Even now there are very few. What Mr. Noble says in favour of the Baudot does not harmonise happily with his enthusiasm for "systematic" Wheatstone. Judging by what is going on in more progressive countries, I think it is a safe prophecy to say that, with the exception of news work, there will not be much "systematic" Wheatstone left in Great Britain in another twenty-five years. It will take something more than "systematic" Wheatstone to arrest the progress of the Baudot and the Murray and other modern printing telegraphs. It is only fair to say that the large majority of British telegraph officials are capable, highly trained men, progressive, energetic, and far-seeing; but their efforts are clogged by prejudice and old routines.

There is one statement made by Mr. Noble that calls for elucidation. He says that in the paper given by Major O'Meara at the first international telegraph conference at Buda Pest, it was mentioned that [in a comparative trial of the Murray automatic, the Wheatstone, and other systems] the saving of line and labour resulted in favour of the Wheatstone, and as regards time the two systems gave equal results. In this matter Mr. Noble's memory seems to have misled him. The information furnished by Major O'Meara to the Buda Pest Conference stated that "The Murray output per operator per hour worked out at 31 per cent. higher than the Wheatstone," and the table of figures given to the conference by Major O'Meara showed that during the trial the Wheatstone handled 12,239 messages and the Murray automatic 12,994, and the number of messages per operator per hour was 27·2 for the Wheatstone and 35·7 for the Murray automatic. These were the actual results of the trials. On the other hand, if Mr. Noble arrives at his statement about the superiority of the Wheatstone by including the estimate of engineering costs of the various

systems, then it must be pointed out that the estimate of engineering costs given at the Buda Pest Conference is utterly misleading and unreliable. It actually charged 3 per cent. sinking fund on interest as well as on capital, and 15 per cent. establishment charges were added not merely to cost of maintenance but also on to interest on capital and on to sinking fund (the latter already swollen by charging it not merely on capital but on the interest on capital), and on top of all that $2\frac{1}{2}$ per cent. for contingencies was added to interest on capital, cost of maintenance, sinking fund, and establishment charges. In view of the composition of this truly remarkable sinking fund, business men can form their own conclusions about the accuracy of the estimated engineering costs. The trials of the various systems are also no longer recent. They took place three years ago, and Major O'Meara mentioned at the Buda Pest Conference that the maximum speed of the Murray automatic during the trials was 95 words a minute. Since that trial three years ago the Murray automatic system has been greatly improved and the Wheatstone has not. The speed of the Murray automatic printer has been increased from 100 up to 200 words a minute, and the practical working speed of transmission has been raised to 150 words a minute. As a further practical comment on Mr. Noble's "saving of line and labour in favour of the Wheatstone," I may draw attention to the official information supplied to me by the Russian Post and Telegraph Administration in regard to the working of the Murray automatic system between St. Petersburg and Omsk. It will be found published as an appendix to this paper. It shows that the Murray automatic has considerably increased the carrying capacity of the line compared with the Wheatstone. Mr. Murray.

The PRESIDENT: I ask you to give Mr. Donald Murray a cordial vote of thanks for his valuable paper.

The resolution of thanks was carried by acclamation.

CHEMICAL ACTION IN THE WINDINGS OF HIGH-VOLTAGE MACHINES.

By A. P. M. FLEMING and R. JOHNSON, Associate Members.

(*Paper received January* 12, 1911. *Read before the* MANCHESTER LOCAL SECTION *February* 14, 1911.)

Introduction.—During the past few years considerable interest has been aroused by the failure of certain high-voltage machines due to a chemical corrosion of the slot insulation. One of the first cases

of this kind was described by Mr. J. S. Highfield,* and the phenomenon has been discussed in connection with papers by Mr. W. H. Patchell † and Professor J. Epstein. ‡ Very little information, however, has been brought forward to enable the insulation of machines to be designed so as to avoid with certainty failure due to this action.

Trouble of this kind has been experienced by practically all the leading European makers of high-voltage machines; and it is of interest to note that in one instance, at least, a machine that had failed on account of chemical action was re-wound for a lower voltage and step-up transformers supplied by the makers gratis.

Having to deal with this problem in connection with the manufacture of high-voltage machines, the authors found it necessary to investigate the numerous factors involved. These investigations, while by no means exhaustive, have been pushed far enough to satisfy practical requirements.

In view of the very hazy notions entertained by many engineers on this matter, it is thought that a review of the principle features may be of interest. In this paper, therefore, it is proposed to describe briefly the general nature of the chemical effects observed, the results of the investigations made, and the method of winding and insulating to prevent chemical action.

Nature of Chemical Effects produced in High-voltage Machine Windings.—The case brought forward by Mr. J. S. Highfield had reference to a 10,000-volt 2-phase alternator, operating with one side of each phase grounded. In this machine the conductors were covered with varnished cotton braid and threaded through solid micanite tubes contained in the slots. Failure occurred after about one year's service. The insulating braiding on the portions of the conductors contained in the tubes at the ungrounded ends and for some distance into the windings had rotted away, leaving a green deposit on the copper. An analysis of the products showed the presence of nitric and some sulphuric acid. The former was attributed to an electrostatic discharge across the air-spaces surrounding the conductors, it being well known that when a discharge takes place in air, ozone and oxides of nitrogen may be formed, and from the latter, nitric and nitrous acids if moisture is present.

The cases investigated by the authors comprised a number of machines, both 2 and 3 phase, where the maximum R.M.S. voltage to ground varied from 3,500 to 7,500. Some of these machines were hand wound through tubes made up of paper and mica. Others had former wound coils insulated in some cases by wrappings of oiled cambric and mica, and in others with paper and mica tubes drawn over the slot portions. While the amount of chemical action varied with the method of insulation employed, the effects produced were in all cases very similar. One example only need therefore be

* *Electrician*, vol. 54, p. 573, 1905.
† *Journal of the Institution of Electrical Engineers*, vol. 36, pp. 79, 108, and 112, 1906.
‡ Ibid., vol. 38, pp. 39, 72 and 93, 1907.

described : that of a 7,500-volt 2-phase generator operating with one side of each phase grounded.

A section of the slot portion of one of the coils in this machine is shown in Fig. 1. The coils were former wound, and the insulating tubes drawn over the slot portions. This necessitated the margin noted in the figure by the variable air-space between the conductors and the inside of the tube. The ends of the tube were sealed by a taping of linseed oil-treated cambric extending around the end portions of the coils.

The machine failed after three years' continuous service due to a short circuit between adjacent conductors near the ungrounded end

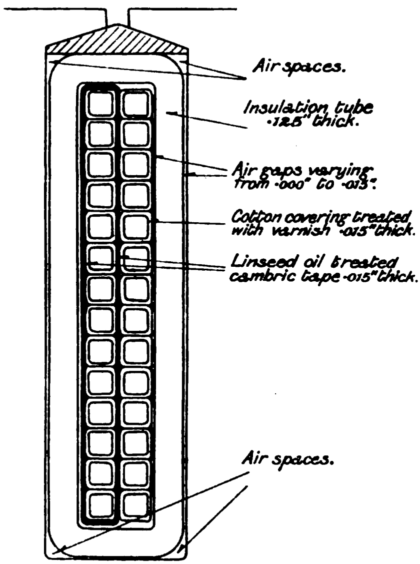


FIG. 1.—Section through Slot of 7,500-volt 2-phase Stator Winding in which Failure occurred due to Chemical Action.

of one phase. This caused a burning of the tube, and ultimately the winding grounded at this point. An examination of the damaged coil showed evidence of considerable corrosion of the conductors. On removing the remaining coils traces of the action were found to extend about half-way round each phase, *i.e.*, to a point having about 3,500 volts to ground. The insulation inside the tubes on the coils at the ungrounded end was very sticky, although all the varnished surfaces had originally been thoroughly hardened.

On the untaped half of the coil (see Fig. 1), the insulation on the conductors was reduced to a greenish white powder, the structure of the cotton covering being entirely destroyed. On the taped half,

the oiled cambric was bleached and very rotten, and the varnish and cotton covering corroded away, except where the taping had been pressed tightly between the conductors and the inside of the tube. The action extended partly between the two sections and about 3 in. beyond the ends of the slots.

The insulating tubes were unaffected chemically, but innumerable perforations were observed in the outside surface in lines marked by the serrated surface of the laminations. This action did not extend nearly so far around the windings as the internal chemical action. On the coils of 3,500 volts to ground the action was very slight; the conductors were only attacked on the untaped section in a few small spots; the oiled cambric on the other section, while affected in patches, had prevented any action on the conductors underneath.

A careful analysis was made of all the affected portions. Traces of nitric acid were found on the coils at the ungrounded end of the winding. On lower voltage coils no nitric or other mineral acid could be detected. The green deposit on the copper underneath the corroded cotton covering proved to be an organic salt.

Chemical action was generally found to be confined to the spaces immediately surrounding the conductors. In the case of an 11,000-volt 3-phase machine, however, strong evidence of chemical action was found in the middle of the slot insulation where a cavity in the material existed. The insulation in this case consisted of a wrapping of mica backed with linseed oil-treated cloth, and the latter had been destroyed on the surface of the cavity exposed to the discharge.

Experimental Investigations.—From investigations of a number of machines insulated in different ways the authors arrived at the general conclusion that the destruction of the insulation was not necessarily due to the formation of nitric acid. For instance, in the case of the 7,500-volt machine already referred to, there were traces of nitric acid on certain of the corroded coils only. Further, the corrosion on the conductors was of an organic nature, and consequently could not have been produced directly by the action of nitric or any other mineral acid that might have been formed.

It was noted that the chemical action only occurred where air-pockets existed in the slot insulation or around the conductors, and only in those machines having high enough voltage to produce a discharge across these spaces. Attention was therefore directed to other effects that might possibly be produced by the discharge, and to any secondary action likely to be set up by the gases or acids thus formed.

In the case of the 7,500-volt machine it was evident that the most likely source of organic acids was the varnish treatment on the insulating materials. The varnish was of a type very largely used in the insulation of windings, and consisted largely of linseed oil and certain resinous gums. Such varnishes dry by oxidation until a hard brittle surface is formed, and under ordinary conditions of drying and heating the oxidation proceeds too slowly beyond the

hardening stage to introduce any element of risk. It is possible, however, under certain conditions, to carry this action much further, causing what is termed super-oxidation, which, in the case of varnishes of this kind, produce an entire change from a hard to a soft pasty condition.

Both the linseed oil as well as the various resinous gums used in the preparation of these varnishes are composed of numerous organic acids, normally so grouped as practically to prevent any free acid action. Under the influence of heat this stable condition is to a slight extent upset and some acid action may occur, as will be noted later. When subjected to super-oxidation, however, the stability of the varnish is ultimately entirely upset, and, while the complete process of oxidation is not fully understood, it is probable that during this change the hitherto inert organic acids are released.

From the pasty nature and general characteristics of the varnish in this machine, super-oxidation of the linseed oil on the cambric, and the varnish on the cotton-covered conductors, had evidently taken place. This was attributable to the presence of ozone, oxides of nitrogen, and nitric acid, all of which are powerful oxidising agents.

To investigate the deterioration of insulation due to all of the products of the air-gap discharge, tests were made to determine the effects of the following :—

(*a*) Intense discharge.
(*b*) Weak discharge.
(*c*) Effect due to the presence of the copper conductor.
(*d*) Direct action of acid fumes.
(*e*) "Breathing" action.
(*f*) Insulation value of the products of the chemical action.
(*g*) Partial destruction of solid insulation by other than chemical action.

For the discharge tests an ozoniser was constructed consisting of a number of glass plates 0·100 in. thick, coated on one side with perforated copper foil, and separated by air-spaces ranging in thickness from 0·03 in. to 0·200 in. An alternating voltage of from 3,000 to 10,000 was applied between adjacent electrodes, and a temperature of about 70° C. maintained throughout the tests. There was access of air to the ozoniser.

Tests were first made on sheet insulating materials comprising untreated and linseed oil-treated cambrics, micanite, plain papers, and papers impregnated with a number of different varnishes, compounds, and waxes. Strips of these materials were suspended in the air-gaps between the plates.

(*a*) *Effect of Intense Discharge.*—With voltage sufficient to produce visible and audible discharge, copper nitrate was formed on the electrodes within three days. The test was continued for about three weeks, when it was found that a number of the varnishes showed marked evidence of deterioration. The samples of untreated cambric

and paper, particularly the former, were riddled with perforations and their fibrous nature very largely destroyed. The linseed oil-treated cambric was partially bleached and very pasty. The other varnish-treated materials had been similarly affected, but to a smaller extent. Papers treated with an asphaltum compound were hardened to a slight extent, but others treated with paraffin wax were apparently unaffected. As regards the micanite samples, the mica itself was unaffected, but some action was observable on the varnishes used for cementing the laminæ together. Comparing the samples with similar materials taken from the machine already referred to, the nature of the deterioration was found to be practically the same in each case.

(*b*) *Effect of Weak Discharge.*—The tests were repeated on new samples, with the voltage reduced to give a barely perceptible discharge. The tests had to be carried on for over six weeks before a definitely marked change in the condition of the materials could be observed. It was then seen, however, that the effects produced were distinctly comparable with those on the similar materials subjected to the intense discharge. The electrodes, while tarnished, showed no trace of copper nitrate. Under these conditions, while ozone was undoubtedly formed, it was evident that no appreciable amount of the oxides of nitrogen was present.

(*c*) *Effect due to the Presence of the Copper Conductor.*—Further tests were made on samples of thin copper ribbon. Certain of these were insulated with cotton covering, some untreated and some impregnated with the various varnishes employed in the previous tests; others had simply a coating of these varnishes or compounds, without any cotton or other insulating covering. The tests were carried out under the two extreme conditions of discharge as before, and similar effects produced on the insulating materials, indicating that the presence of the copper had no direct influence on the deterioration of the insulation.

As will be discussed later, certain varnishes—notably those of the linseed oil gum type—produce a slight green organic deposit on copper, independent of any chemical effects produced by discharge. In the case of conductors treated with such varnishes and exposed to discharge in the ozoniser until marked deterioration of the varnish took place, this organic deposit was found to be considerably increased.

(*d*) *Direct Action of Acid Fumes.*—The results of the foregoing tests indicated that, except in the rapidity of the action, the effect on the insulating materials was generally the same with either ozone, oxides of nitrogen, or nitric acid. In order, however, to eliminate any other effects of the discharge, similar samples of insulation were exposed to the action of nitric acid fumes. The result was a very rapid deterioration of the insulation, distinctly comparable in character with similar materials tested in the ozoniser. It was noticeable, however, that in the case of untreated fabrics and papers the disintegration was not quite so complete, due apparently to the fact that there

was no electrostatic dispersion of the particles. It was further noted in the case of samples of insulated copper, that if the action was allowed to proceed too rapidly, the insulating coverings, hitherto impervious to acid fumes, lost their protective value, and the copper became subjected to direct acid action. The nitrate then formed destroyed any evidence of organic salts.

(*e*) *Effect of "Breathing" Action.*—The occluded air in machine windings is liable to continual displacement, due to the alternating heating and cooling setting up what has been aptly termed "breathing" action. To determine the effect of this on the amount and rapidity of the chemical action, tests were made on short lengths of insulated conductors inserted in glass tubes, and generally comparable as regards air cavities with a high-voltage coil. Sufficient voltage was applied to produce an audible discharge in the air-spaces between the conductors and a metal sheath tightly fitting the outside of the tube. The temperature of the tubes was varied between 15° and 75° C., and the conditions in this respect were roughly comparable with those in machine windings.

Three tests were made: in the first, the ends of the tubes were left open, and in these the chemical action went on freely. In the second, the ends were carefully taped up and varnished, and in this respect comparable with the ordinary method of sealing the ends of slot insulation. In this test the chemical action proceeded steadily but much more slowly than in the previous case.

In the third test, the tubes were hermetically sealed and maintained at a steady temperature. While the discharge was quite as intense as in the previous tests, the small volume of air produced very little chemical action, and this proceeded only for a short time, as the air could not be replenished by "breathing."

(*f*) *Insulation Value of the Products of Chemical Action in Windings.*—Pressure tests on the decomposed material taken from coils on which no nitric acid had been found showed these to be of comparatively high insulating value, and not dangerously hygroscopic. Where there was nitric acid, however, and it had attacked the copper, the nitrate thus formed, being of a highly deliquescent nature, was readily conducting. Also where free acid was present in the decomposed insulation, this, for the same reason, considerably increased the conductivity.

(*g*) *Partial Destruction of Solid Insulation by other than Chemical Action.*—In considering the voltage distribution across dielectrics made up of layers of different insulating materials, it was noted that, apart from effects produced in air-gaps, the solid insulation might in some way be directly affected. For instance, where the dielectric is composed of two layers of different materials, one of high and the other of low specific inductive capacity, the voltage across the latter might under certain conditions be higher than its disruptive value, although the insulation as a whole were quite able to sustain the entire voltage applied. To determine the effects on solid insulation under these conditions, tests were made with a dielectric composed of sheets

of equal thickness of glass and paper. Tests were first made to determine the voltage required to puncture the paper. Voltage was then applied to the entire dielectric so as to give a component (about 75 per cent. of the total voltage) across the paper, computed to be well above that required to produce its disruption. The result was to riddle the paper with minute perforations, which consequently reduced its insulation strength to a fraction of the original value, as shown by breakdown tests that were subsequently made. These tests were carried out with well dried paper. It was interesting to note that with the paper in its normal condition, *i.e.*, containing about 7 per cent. of moisture, the specific inductive capacity was increased sufficiently to reduce the component of voltage so much that no perforations were produced in the paper until a considerably higher test voltage was applied.

Data derived from Investigations.—From the results of the foregoing tests and the investigations on machines that have failed, the following data have been established :—

1. No case of chemical action has been observed on windings having a lower voltage than about 3,500 to ground, as, for instance, 6,000-volt 3-phase star-connected machines.
2. Chemical action only occurs where air-pockets are present, and then only when the voltage across them is high enough to produce a discharge.
3. While the action commences on the surfaces of the insulation exposed to air-pockets, the gases produced by the discharge may be carried beyond the zone where they are formed, and produce action on other portions of the insulation outside the slots. While a discharge undoubtedly occurs between the outside of the insulation and the laminations, very little chemical action is to be expected on the exposed surface, since the gases formed can freely escape, and, further, the insulation is not usually of a kind readily affected.
4. The action of the products of the air-gap discharge—whether these be ozone, oxides of nitrogen, nitrous or nitric acid—on the insulation is most commonly one of oxidation, and the effects produced on different materials are as follows :—

Untreated cellulose materials have their fibrous structure readily destroyed, and disintegration follows.

The oils and gums used in the preparation of insulating varnishes are practically all subjected to super-oxidation and as a result yield organic acids. Of these materials, linseed oil is most readily affected.

Certain asphaltum compounds are attacked only to a limited extent, and paraffin wax appears to be quite unaffected.

Mica is itself unaffected, but the cements used in building it up are liable to attack on exposed surfaces.

5. The production of nitric acid is not essential for deterioration of the insulation to occur, although when it is produced, the action is greatly accelerated.
6. The final disintegration of varnish-treated materials is greatly accelerated by the action of the released organic acids.
7. Failure due to chemical action is almost invariably the result of a short circuit between turns, and not, as is sometimes supposed, of a breakdown of the slot insulation between windings and ground. The short circuit is caused either by a destruction of the insulation on the conductors, which allows the turns to make actual contact, or by the hygroscopic and therefore conducting matter formed between conductors when nitric acid is present.
8. Unless the air in the cavities of the winding is replenished by "breathing," the chemical action will cease.
9. When the stress on insulation is very high, deterioration other than that due to chemical action may be produced. Thus, if the insulation is made up partly of materials such as mica, of high specific inductive capacity, and partly of material such as paper, of low specific inductive capacity, the insulating value of the latter may be destroyed without the insulation as a whole breaking down.

On the basis afforded by these data, the precautions to be taken in order to prevent failure due to chemical action will be discussed under the following heads :—

Potential gradient.
Safe working stress for any method of insulating.
Special methods of insulating for very high stresses.

Potential Gradient.

It is well known that the distribution of voltage across a dielectric made up of layers of a number of different materials varies across each layer directly as the thickness and inversely as the specific inductive capacity. Each layer may be considered to represent the dielectric of a condenser, and the total thickness of insulation a number of condensers in series.

The slot insulation in a high-voltage machine usually consists of a number of layers of different materials, as shown, for instance, in Fig. 1, the specific inductive capacity of the materials used in that case varying from 1 for air to about 6 for the mica. From this it follows that where air layers exist, the potential gradient is much steeper across them than across the solid insulation.

It would be of interest to know exactly to what stress the air-gaps are subjected in the various cases occurring in practice. This cannot

be ascertained directly, however, as will be seen from the following considerations :—

> There may be several air-gaps in series, as, for instance, those around the conductors, interstices in the insulation, and the external gap between the insulated coil and the laminations, all of which may vary in thickness at different points. While machines are sometimes designed with the slots concentric with the assembled conductors, such cases are rare, and in the rectangular slots generally used, the distribution of voltage will vary at different points around the periphery of the slot portion of the coil.
>
> Even if it were possible completely to fill the space between the conductors and iron with layers of homogeneous material, the potential gradient would be steepest across the layers near the conductors, since these have a smaller area and therefore a smaller capacity than those on the outside of the coil. This is accentuated at the corners by the small radii, but the steepness of the potential gradient will be minimised at these points if square-cornered slots, as shown in Fig. 1, are used. From this it follows that it can only broadly be stated that the stress across the air layers near the conductors is greater than that across the external air-gaps between the insulation and the iron.
>
> The specific inductive capacity of the composite solid insulation varies considerably according to the method of manufacturing, and if untreated paper is used its value in this respect varies according to the state of dryness.

Most of the above factors are affected by the temperature variation- occurring under running conditions, and any one of them is sufficient to prevent an accurate determination of the potential distribution across the air-spaces.

While it is thus seen that the actual stress across the air-gaps cannot be computed for practical cases, the manner in which the intensity of stress is affected by the variables introduced, according to the method of winding and insulating, can be readily shown.

The principal variables to be considered are the following :—

(*a*) Radial thickness of slot insulation.
(*b*) Specific inductive capacity of the materials.
(*c*) Thickness of air-gap.

(*a*) *Effect of varying Radial Thickness of Insulation.*—In Fig. 2 is shown the distribution of stress across a composite insulation, made up of a thickness S_1 of solid material, having a specific inductive capacity, say, of 4, and a thickness G, representing the air-gap next the conductor. With a voltage V applied across the entire insulation the potential gradient is indicated by the slope of the line A B C, and the voltage across the air-gap by v_1.

If, now, the thickness of solid insulation is increased from S_1 to S_2 and the air-gap maintained as before, the potential gradient is then indicated by the line D E C, and the voltage across the air-gap is reduced from v_1 to v_2. The difference in stress across the air-gap in

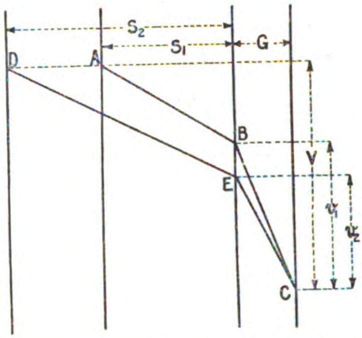


FIG. 2.—Potential Gradient across Composite Insulation. Effect of varying Thickness of Solid Portion.

the two cases is seen by comparing the slopes of the lines B C and E C.

(b) *Effect of varying the Specific Inductive Capacity.*—In Fig. 3 is shown a composite insulation consisting of a thickness of solid insulation S and air-gap G.

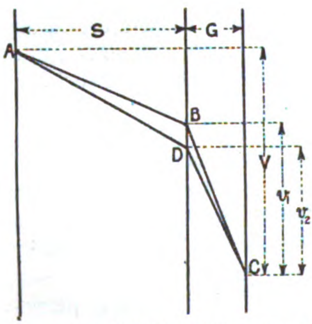


FIG. 3.—Potential Gradient across Composite Insulation. Effect of varying Specific Inductive Capacity of Solid Portion.

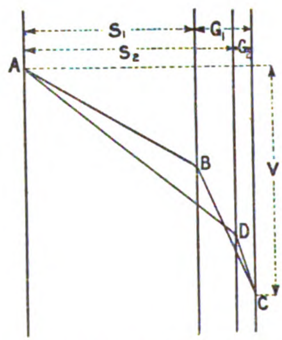


FIG. 4.—Potential Gradient across Composite Insulation. Effect of varying Thickness of Air-gap.

If the specific inductive capacity of the solid insulation is 6, the potential gradient for an applied voltage V may be represented by the line A B C, giving a voltage across the air layer of v_1. If the specific inductive capacity can be reduced by the substitution of a different

solid material to, say, 4, the potential gradient will be changed to that indicated by the line A D C, the voltage across the air-gap then being reduced to v_2. That is to say, for given thicknesses of solid insulation and air-gap, the lower and specific inductive capacity of the former the less will be the stress across the latter.

(c) *Effect of varying the Thickness of Air-gap.*—Considering the insulation to be made up as shown in Fig. 4, by a thickness S_1 of solid insulation and G_1 of air-gap, the potential gradient is represented by the line A B C. If, while maintaining the same total thickness of insulation, that of the solid material is increased to S_2, reducing the air-gap to G_2, the potential gradient is altered to that indicated by the line A D C. Under these conditions the stress across the air-gap is increased as shown by the slope of the line B C compared with that of D C.

For the sake of simplicity, the solid insulation referred to in the above examples is assumed to be homogeneous and the electrodes to consist of perfectly parallel plates so that a uniform field exists between them.

Safe Working Stress for any Method of Insulating.

While chemical action has been observed on windings having a voltage to ground as low as 3,500, there are many machines that have operated satisfactorily for years at voltages as high as 10,000 to ground. Further, it is interesting to note that as far as the authors have been able to ascertain, all the machines that have failed through chemical action have been of European make. No instance of an American machine giving trouble could be found, although inquiries were made of several leading American engineers who were interested in this matter.

The thickness of slot insulation would appear to afford the simplest explanation of the freedom from chemical action of comparatively low-voltage machines. It has, for mechanical reasons, to be so great in proportion to the voltage that the stress across occluded air-spaces is probably well below that at which a discharge commences. To ascertain to what extent this factor applies for higher voltages, the radial thicknesses of slot insulation were taken for a number of the machines noted above that were considered to be perfectly safe, and compared with those of machines that had failed. These machines were in no way specially insulated to withstand chemical action, and other than as regards radial thickness of slot insulation, were generally comparable with each other.

From these data it was seen that, for a definite voltage, there was a fairly definite radial thickness of insulation that could be considered safe irrespective of the method of insulating. The curve in Fig. 5 was plotted from the figures thus obtained and from the radial thicknesses of insulation commonly used for lower voltage machines. This curve shows the relation between voltage to ground and average voltage stress across the slot insulation. The stress is expressed in

volts per mil of the total radial space in the slots between copper and iron.

While the authors know of no case where failure has occurred at a stress as low as the maximum indicated on the curve, they have observed, in several cases, definite traces of chemical action where the

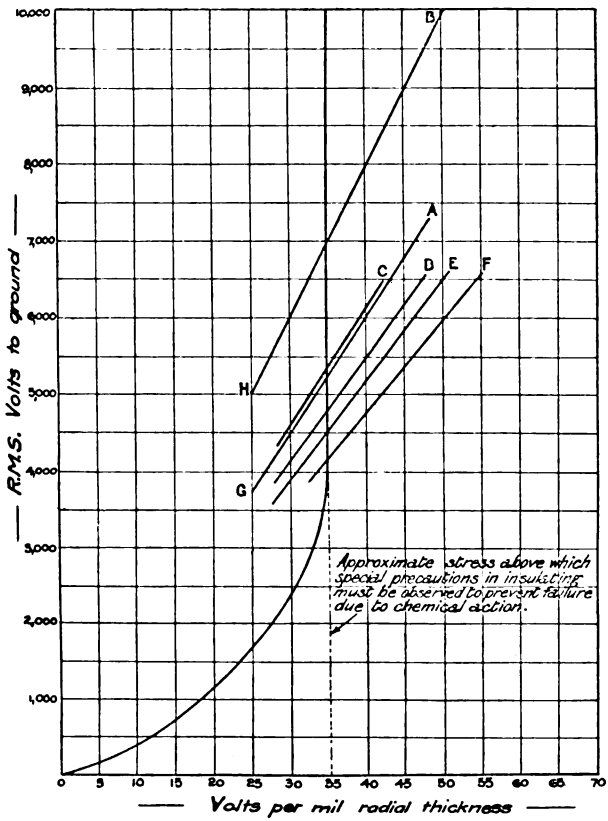


FIG. 5.

stress has been as low as 25 volts per mil. The action, however, has been too slight seriously to impair the life of the insulation.

The straight lines cutting the curve indicate, for a number of different makes of machines, the range of voltage over which chemical action has been observed. All these failures have occurred near the extreme end of the winding, and the stresses at these points are indicated by A B C D E and F. The line A G refers to the 7,500-volt 2-phase machine already referred to, and B H the example described

by Mr. Highfield. It should be noted that the lower extremities of the lines only represent approximately the stresses at which chemical action ceases, as at these low voltages the evidence is very indistinct.

The value of 35 volts per mil shown on the curve in Fig. 5 may be considered to represent the safe average stress even for machines affording every facility for chemical action to take place. In view of the effects of the variables already noted, it will be appreciated that many machines may operate safely at a much higher stress than this without being specially insulated to prevent chemical action.

Special Methods of Insulating for very High Stresses.

With improvements in insulating materials and the methods of applying them, together with the necessity for high copper space factors incident to keen competition, the tendency among European makers has been to force the stress on the slot insulation much higher than has been the general practice in America. In dealing with stresses higher than about 35 volts per mil of total slot insulation, it is necessary to eliminate air-spaces as far as possible, to employ insulation that is not readily affected by chemical action, and to reduce to a minimum the stress across any existing air layers. The authors know of several machines that have operated safely for years at an average stress as high as 60 volts per mil where the proper precautions have been observed. It should be noted, however, that stresses reached when pressure-testing machines for such severe working conditions fall within the range of those liable to produce partial breakdown of insulation in the manner already noted.

The practical problems involved in insulating for very high stresses will be considered under the following heads :—

(*a*) Impregnation of windings.
(*b*) Arrangement of conductors in coils.
(*c*) Best type of coil.
(*d*) Sealing slot insulation against "breathing."
(*e*) Selection of materials.
(*f*) Special methods of reducing the stress across the air layers.

(*a*) *Impregnation of Windings.*—The importance of this process in general insulation work is now fully appreciated, but the limitations as regards the filling of interstices in windings is by no means generally recognised.

In the most modern method of impregnating coils, these are dried under vacuum in a suitable steam-heated chamber to remove moisture and occluded air; varnish or molten compound is then drawn in and forced into the coils under an air pressure of 50 to 60 lbs. per square inch applied for several hours; the surplus impregnating material is then drawn off. The ideal result of such treatment is a completely solid, moisture-proof coil. Unfortunately such a

result cannot be obtained commercially. If varnish is used as the impregnating material, interstices must necessarily be left when the solvent, which forms a considerable portion of the bulk, is expelled. When compounds are used, the choice of material is limited by the melting-point, which must be so high that there is no tendency to flow at the maximum working temperature of the windings. At the same time, the compound must become very fluid at a temperature well below that at which the cotton or other insulating coverings to be impregnated become damaged. Further, it must not become brittle at the lowest temperature to which it may be subjected in service.

Within the limits imposed by these requirements, it is practically impossible to obtain a material, otherwise suitable, with a low coefficient of expansion. Ordinarily there may be as much as 10 per cent. difference between the volume at normal and that at the impregnating temperature. Interstices will therefore be formed by contraction of the compound when it cools. Further, where there are air-pockets in the interior of the coil other than of dimensions comparable with the capillary tubes in the fibrous materials, it is impossible to fill them except under very prolonged treatment. This is due to the exceedingly small and tortuous channels through which the impregnating material has to travel. Moreover, it is nearly impossible within practical limitations to impregnate a completely insulated armature coil on the slot portions, since the insulating materials ordinarily used on these parts are almost impervious to impregnating compounds; and further, a much higher pressure than can ordinarily be applied is necessary to force the compound in from the ends throughout the length of the coil. It therefore becomes necessary to impregnate the formed coils of high-voltage machines before the slot insulation is applied. Even when this is done, additional processes are required to ensure that all spaces between conductors are properly filled, and a smooth plane surface prepared upon which to press the slot insulation. A further treatment by impregnation, after completely insulating, is desirable, as a means of sealing the ends of the insulation on slot portions and to give a moisture-resisting covering to the entire coil. These precautions, while affording a solid coil at normal temperatures, only partially achieve the desired result, since the whole of the insulation swells when the windings are heated and does not contract and occupy its original position on cooling. Cavities are liable therefore to be formed around the conductors into which air will eventually percolate. Moisture may also be absorbed by the breathing action.

(b) *Arrangement of Conductors.*—Owing to the difficulty of making a solid coil by impregnating and filling processes, it is necessary to consider the best arrangement of conductors which will reduce to a minimum the inter-spaces to be filled. This is further necessary inasmuch as spaces, other than those across which a discharge may take place, act as a reservoir and replenish the air acted upon by the

discharge. This occluded air also assists in setting up breathing action.

Rectangular conductors should be used and when possible be chosen of such a shape as to give a single section arrangement, as shown in Fig. 6. Even when it is necessary to use two rectangular conductors in parallel side by side, as shown in Fig. 7, this arrangement is generally preferable to multi-section coils. A comparison of various arrangements common for coils having the same number of conductors, and the same cross-section of copper, is shown in Figs. 7, 8, and 9.

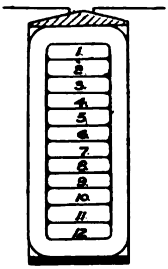


FIG. 6.

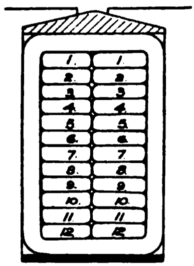


FIG. 7.

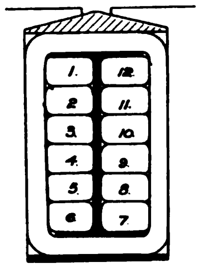


FIG. 8.

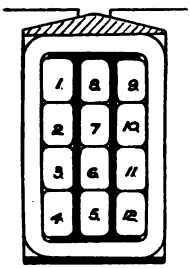


FIG. 9.

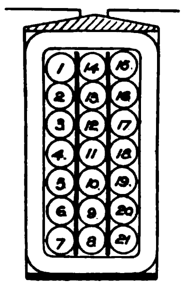


FIG. 10.

Methods of arranging Conductors in Slots.

As regards freedom from inter-spaces, the advantage of coils wound with rectangular conductors is seen by comparing Figs. 9 and 10. The single section arrangement with rectangular conductors gives a very solid coil, mechanically well adapted to withstand the handling during the application of the external insulation. As pointed out earlier in the paper, failure from chemical action is almost invariably the result of short circuits between conductors: it is therefore desirable that the voltage between adjacent turns be kept as low as possible. It will readily be seen that the single section coil is ideal in this respect, and further, this formation is such that turns of widely differing

potential cannot be readily displaced to make contact during handling or in the insulating process.

To further safeguard against short circuits, the conductors, where number and size permit, should have their insulating coverings reinforced on the slot portions by separating strips of mica or other insulation not affected by the chemical action. The single section type of coil is best adapted to this method of reinforcement, since in the multi-section coils the conductors are usually too narrow effectively to retain the separators during handling. A typical example of a single section coil of an 11,000-volt 3-phase star-connected machine, insulated in this way, is shown in Fig. 11.

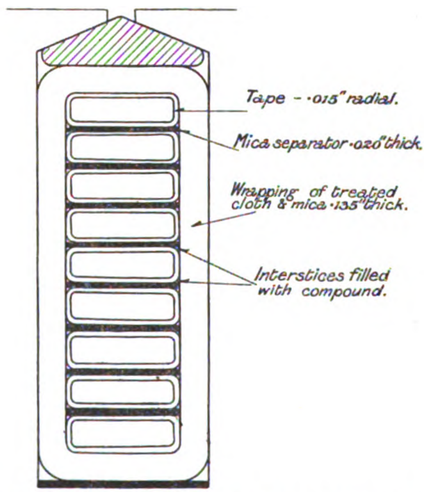


FIG. 11.—Section through Slot of an 11,000-volt 3-phase Star-connected Generator. Showing best method of Grouping and Insulating for High Stresses.

It should be noted that even with the best arrangement of conductors, it is generally impossible to wind coils so as to present a perfectly plane surface, and interstices varying in length according to the size of coil and in thickness up to about 0·030 in. will here and there occur. These require filling by means of such processes as have already been described before the external insulation is applied. Further, some interspaces in multi-section coils due to the rounding of the corners of the conductors must inevitably occur.

When the conductors in a coil are so small and numerous that separators cannot be used between them, the coils are usually so weak mechanically that turns are liable to be displaced. Such coils should be insulated to "ground" so heavily as to bring the stress within the safe limit of 35 volts per mil, or, alternatively, the machine

be wound for a low voltage and step-up transformers used. It should be noted in connection with such risky coils, that when used for high-voltage machines, surges or other causes of concentration of potential between terminal turns are specially likely to produce short circuits at these points, since it is here also that the insulation between turns is most likely to be weakened by chemical action.

(*c*) *Best Type of Coil.*—The slot insulation of a formed and solidly impregnated coil can best be applied as a wrapping, hot-ironed to give a solid insulation free from occluded air. As already noted, while such an insulated coil, when cold, can be obtained free from air-spaces, when subjected to the running temperature of the machine the insulation readily swells and takes up the winding clearance allowed between the insulated coils and iron. It also tends to bulge into ventilating ducts in the core. Air eventually penetrates into the spaces thus formed, and although these may be very minute, "breathing" is set up.

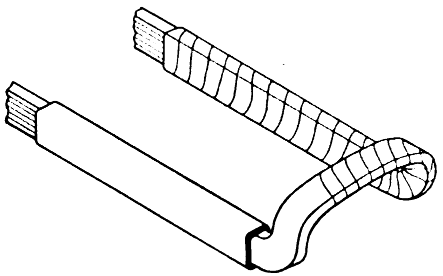


FIG. 12.

From the necessity of reducing to a minimum the amount of air space in windings, it will be seen that coils wound on formers, impregnated and completely filled and insulated before placing in the slots, afford the best type for safeguarding against chemical action. Where electrical considerations permit, open slots are preferable to semi-closed, since a smaller winding clearance can be allowed in the slots and the swelling of the insulation consequently reduced to a minimum.

A formed coil for use in semi-closed slots is shown in Fig. 12 and one for open slots in Fig. 13. From these figures it will be seen that the second type of coil possesses the additional advantage that it can be entirely insulated before placing in the machine and the sealing of the ends much more completely effected.

Coils wound directly into the machine by threading the turns singly through insulating tubes, while perhaps more commonly employed than any other type, are quite unsatisfactory for machines in which the stress across the slot insulation exceeds about 35 volts per mil. In such coils round wires, as shown in Fig. 10, generally have to be used, as with rectangular wires the risk of abrasion of

the coverings during winding is too great. This, and the internal winding clearance, causes a considerable amount of interspace in the coils, and except where the machines are small enough to be impregnated as a whole, there is no satisfactory way of filling the interstices.

(*d*) *Sealing of Slot Insulation against "Breathing."*—Breathing action in coils takes place to a much greater extent than is ordinarily considered possible, and is difficult to prevent except with completely formed and separately insulated coils of the type shown in Fig. 13. With this type, when the interstices are reduced to a minimum by suitably impregnating the coil, the breathing can be more or less prevented by extending the tape on the ends of the coils over the slot insulation, applying several layers of tape, and varnishing each separately, or impregnating the completely insulated coil with compound.

The application of tape or compound after coils are in place in slots—as, for instance, in the hand-wound type—cannot be made to

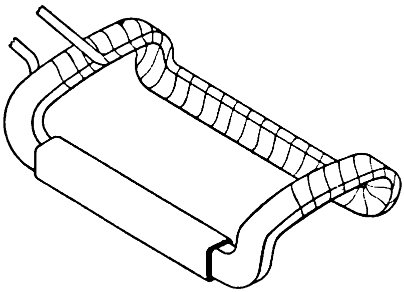


Fig. 13.

seal up the ends of the slot insulation effectively enough permanently to prevent breathing.

(*e*) *Selection of Materials.*—Since occluded air and breathing cannot with certainty be avoided, some additional safeguard must be sought by using, as far as possible, those insulating materials that are least affected by the products of the air-gap discharge. As already shown, chemical action may be produced at an average stress as low as 25 volts per mil, and above this stress such readily oxidisable insulation as linseed oil-treated cambric should be avoided. For such stresses the cotton covering or conductors, or other cellulose material, should be impregnated with molten asphaltum compound rather than with varnishes of the linseed oil type.

The same kind of asphaltum compound should be used to fill the interstices in the coil. For this purpose, as well as for impregnating the insulation, paraffin wax would be invaluable on account of its inert nature, if its low melting-point did not preclude its use. Un-

treated cotton covering and other cellulose materials are generally excluded from machine windings for any voltage. From the tests noted in the early part of the paper it will be seen that it is particularly necessary to avoid their use in high-voltage machines.

For the separators between adjacent turns, mica appears to be the most suitable material. As regards external insulation, mica backed with treated paper or fabric is very satisfactory. With this material, the mica surface should be placed nearest the air-gap so as to shield the backing material from the chemical effects resulting from a discharge.

(*f*) *Special Methods of reducing Stress across the Air-gap.*—As already shown in reference to Fig. 3, a low stress across the air-gap can be obtained by using solid insulation of low specific inductive capacity. Unfortunately, however, there are no materials, having very low specific inductive capacity, that are otherwise suitable for the insulation of high-voltage coils. Consequently the air-gap stress relative to that across the solid insulation cannot be reduced in this way.

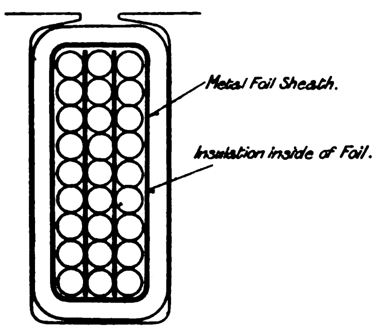


FIG. 14.—Showing Method of Preventing Discharge across the Air-gap.

A method that has been proposed for minimising the air-gap stress is shown in Fig. 14. This consists of winding between the inner layers of the slot insulation, a sheet of metal foil extending the full length of the slot and completely enclosing that part of the coil. This is connected to one of the conductors, preferably at about the centre of the coil. Under these conditions the stress between the windings and ground is concentrated on the solid insulation between foil and iron, rendering that across the air-gap practically negligible. To prevent any action due to the external gap, a similar sheet of foil may be used around the outside of the coil and grounded to the iron.

Theoretically this method is quite sound and should enable the stress on the solid insulation to be pushed up to the limits determined by breakdown considerations. It might be specially used to advantage in the case of hand-wound coils for very high voltages. The authors,

however, know of no instance where it has been used in machine work. The method would introduce several practical disadvantages, as, for instance, the difficulty of ensuring, under all conditions, perfect contact between foil and slot insulation, and the effective insulating of the foil from the conductors without requiring too much insulation space. Except under special conditions, it is very doubtful whether the method is commercially practicable.

Chemical Action in Windings other than that due to High Voltage.—There is a form of chemical action that is often confused with that produced in high-voltage windings. This is liable to occur on windings whether they are in service or not. It is to be found on varnish-treated coils only, and is indicated by a greenish discoloration of the copper conductors and of the cotton or other insulation surrounding them.

Though not exclusively so, the action is mainly confined to varnishes of the linseed oil type, and is due to the presence of weak organic acids. The extent of the action depends on the quality of the varnish, the temperature at which it is dried, and the condition of the insulating covering as regards moisture. With the best makes of varnish, and the most favourable conditions of drying, it is impossible absolutely to prevent this action, unless the copper is protected by a coating of tin or suitable enamel.

Considerable apprehension is often caused by this green discoloration in coils. The authors, however, have never known of a case where it could be demonstrated that this action had appreciably lowered the insulating value or impaired the mechanical properties of the insulating covering, or, in fact, afforded any evidence of its presence, except by the colour produced. While this evidence is only appreciable with more or less transparent varnishes, the action producing it must also occur with the black varnishes of the same class. In general, these linseed oil gum varnishes are eminently suitable for the insulation of windings other than those where chemical action due to high stresses is likely to occur.

Conclusions.

1. For the range of voltages at present used, failure of machines from chemical action is not to be expected when the average stress across the slot insulation is less than about 35 volts per mil, with any of the methods of winding and insulating commonly employed. With windings having a voltage of less than 4,000 to ground, the stress is usually kept below this limit by the ample thickness of insulation required for mechanical reasons.

2. A much higher average stress than 35 volts per mil of slot insulation is safe when the size and number of conductors permits the best method of grouping and insulating to be employed, and when special precautions are observed as to the kind of materials used and the proper filling of interstices.

3. Failure due to chemical action is almost invariably the result of a short circuit between turns of the windings, and not of a breakdown through outer insulation to ground. On this account mica or other material which is unaffected by chemical action should be used between turns whenever this action is likely to occur.

4. While failure due to chemical action may be prevented by proper precautions, even when very high stresses are employed, there is in such cases some risk of producing a partial breakdown of the slot insulation when the ordinary presure tests are applied. Such weakening is likely to occur when layers of material of high and low specific inductive capacity are used together, the insulation value of the latter being destroyed. In this connection it should be noted that a presure test affords no criterion as to the safety of windings against chemical action, since the stress at which the latter takes place is usually far below that at which disruption of the insulation occurs.

5. The green discoloration which frequently occurs on coils of any voltage treated with linseed oil gum varnishes should not be confused with the chemical action due to the products of the air-gap discharge which takes place in high-voltage windings only. Such discoloration is quite harmless with the best makes of varnishes.

The authors desire to express their indebtedness to Mr. J. S. Highfield for the interesting data supplied in connection with his observations of chemical action in high-voltage machines.

Discussion before the Manchester Local Section.

Mr. C. J. Beaver: Some time ago I had the privilege of making an independent examination of some windings which had failed on a high-voltage generator which had worked for three years at a pressure of 5,500 volts to ground, and I can fully confirm the authors' observations both as to the appearance and distribution of the affected parts, and also with regard to the analytical identification of the products. For instance, I had no hesitation in coming to the conclusion after analysis that the very distinctly acid substances found on the varnished cambric and varnished cotton coverings were superoxidation products of linseed oil, because they corresponded very closely with the products formed by exposure of linseed oil to air and sunlight at ordinary temperatures for periods of several years. For this reason, and for the further reason that only traces of nitric acid or nitrated substances could be found, I am inclined to agree with the authors that the simple formation of ozone could be held responsible for practically all the damage. With regard to the authors' conception of the composition of linseed oil and the changes which may occur in it, while I agree that the complete process of oxidation is not fully understood, I can hardly regard their statements on the subject as quite accurate. Linseed oil does not consist of organic acids, but of glycerides of certain fatty acids which are chiefly of the linolic and linolenic series. Certain variations in the process of extraction and manufacture cause variations Mr. Beaver.

Mr. Beaver. in the proportions of glycerides of other series which may be present. This in turn will cause variations in drying properties and may in some cases account for the presence of free fatty acids which will attack metals to some extent. The drying properties are important from the machine builders' point of view, because chemically the oil films in drying pass through various stages of rancidity until they arrive at what used to be regarded as the final state of oxidation. This supposed fully oxidised body is known as linoxyn. It is solid, somewhat flexible, and from the physical point of view excellent for the purpose we are considering to-night. It is quite neutral, and insoluble in the solvents in which at lower stages of oxidation it was previously soluble. It is a very stable body, and many experiments I have made show that the superoxidation referred to in the paper can only be brought about under very severe conditions, such as exposure to nascent ozone. The desirability of thoroughly drying, *i.e.*, converting the films into linoxyn as quickly as possible, is therefore important, because the period during which simple chemical action on the conductors may occur is thereby minimised, and also because the action of ozone may possibly split up the constituents more easily before they reach the most stable stage represented by linoxyn. A characteristic feature of the superoxidised products is their solubility in water. Their pronounced acidity indicates that they are probably of comparatively low molecular weight. They readily attack fabrics and metals. The hydrocarbon compounds which the authors find to be comparatively unattacked by the air-gap discharge are not very encouraging from the practical point of view, and the authors are, judging by their remarks under the heading of "Impregnation of Windings," fully aware of the physical difficulties, firstly of applying them, and secondly of keeping them in place under running conditions. Materials such as asphaltum, which have to be applied in a molten state, must always be regarded as fluids, and the very properties which minimise their fluidity under working conditions—*e.g.*, high melting-point and viscosity, militate against their original application to the windings and the interstices. Moreover, it may not be generally known that cotton yarns or fabrics which are impregnated with a varnish made by simply dissolving, say, asphaltum in a suitable solvent, stand the effects of heat much better than similar yarns or fabrics impregnated with the same compound in a molten state. The reason for this is probably that in the former case the individual fibres are better impregnated than in the latter case. In view of these considerations it would appear to be generally better to use varnishes and varnished fabrics and to keep the maximum stress within the limits illustrated in Fig. 5. I am much interested in the proposed method of preventing discharge across air-gaps shown in Fig. 14, because the principles have already been successfully applied in cable practice for very high voltages. First, the foil applied over the slot insulation and grounded to the iron is an exact parallel to the light metallic sheathing which I pointed out some ten or eleven years ago as the cure for static discharge troubles which were then commencing to be

encountered on cables. And, secondly, the metallic layer between the inner layers of slot insulation and connected to one of the conductors at an intermediate voltage-point, is also an exact parallel to the intermediate potential-distributing layer which my firm use in cables for working pressures of 50,000 to 100,000 volts. The method probably does not lead to such marked economy of insulating material in machine windings as in cables, but it should certainly be worth pursuing. Mr. Beaver.

Mr. MILES WALKER: A very marked case of the production of nitrate of copper occurred during some tests on the insulation of condensers intended for high-voltage work. During the test which took place in air there was a brush discharge across certain air-spaces, due to the capacity current flowing into the condenser. This was very analogous to the cases mentioned by the authors. It became interesting to inquire into the exact nature of this current which flows through the ordinary paper insulation. It appears to be in part a dielectric current and in part a conduction current. The wave-forms of the current and E.M.F. were plotted by an accurate method which enabled their exact shape and phase relation to be seen. By integrating the current curve, the curve of quantity of electricity supplied to the condenser was obtained, and plotting the E.M.F. as abscissæ and the quantity as ordinates a closed curve was obtained whose area represented work lost per cycle in the insulation. This curve was an ellipse, from which it can be shown that everything goes on as if the loss is due to ohmic resistance. The insulation, in fact, behaves exactly like a number of condensers placed in series with a number of resistances. Now, it is found from experiment that resistances are very much decreased as the temperature is raised, so that the current flowing through the condenser depends very greatly upon the temperature. It cannot really be decided what thickness of insulation will be necessary to cut down the brush discharge until the temperature is specified. The authors' figures may be taken at the normal machine temperatures. Large pads of insulating material were placed in an oven in which they could be raised to any desired temperature, and measurements of the losses occurring were taken by an electrostatic wattmeter at different voltages and different frequencies. Some of the results of these tests have been published in the *Transactions of the American Institute of Electrical Engineers.** It was possible to plot curves showing the relations between the watts lost per cubic inch of material, the voltage per inch, and the temperature. From these curves the temperature to which a block of insulation would rise if the cooling conditions were sufficiently well ascertained could be determined. The interesting result is that for a given voltage per inch, a given surrounding temperature, and a given rate of cooling, the conditions may either be such as to result in a steady final temperature of the insulation, or the conditions may be such that the rate of production of heat is greater than the rate of dissipation of heat, in which Mr. Walker.

* *Transactions of the American Institute of Electrical Engineers*, vol. 19, p. 1047, 1902.

Mr. Walker. case this temperature rises until a breakdown occurs. On a large number of tests made on the type of insulation used in high-voltage transformers, it was found that where breakdown occurs through the application of high voltage the effects could be shown to be due to the rise in temperature owing to the conditions being such as to bring about a gradual accumulation of heat. Had the cooling conditions been better the same insulation would have withstood a higher voltage; in a word, the breakdown of paper insulation is generally due to burning, and the voltage it will stand depends upon the cooling conditions. This is the one reason why a thin piece of insulation placed between two plates will withstand so many more volts per inch than a thick piece. If the cooling conditions were sufficiently good the very thinnest piece of paper would withstand very high voltages, and, on the other hand, if the cooling conditions could be made sufficiently bad a very thick piece of insulation could be broken down by a small voltage. The same law is true in the limitation of brush discharge; we must have regard to the rate of production of heat and the rate at which it can be carried away.

Mr. Cramp. Mr. W. CRAMP: I might first point out that though no such statement is made, it is evident that alternating stresses alone are considered. The paper would require considerable modification, I think, if high-voltage continuous-current machines were included in its purview. While the general results of the discharge taking place through the machine windings are, no doubt, correctly expressed by the authors, yet I think one very important point has been overlooked. It seems to be their opinion (and Mr. Beaver seems to agree) that nitric acid is not necessarily produced by the so-called "silent" discharge. This, however, is a mistake, for, no matter how weak the discharge, there is always a certain amount of nitrogen oxides produced, though the weaker the discharge the less the amount is. Again, it has been stated that the ozone produced would alone be sufficient to account for all the effects observed. I do not think this is true, for, although chemically produced and chemically pure ozone would, no doubt, set up the same action, it could not possibly act anything like so vigorously; it could not, in fact, produce the same results in the same time. It is now well known that when ozone is produced by the electric discharge in air there is an extremely active and unstable compound of nitrogen which makes its appearance. This gas is thought by some to be a higher oxide, having the formula N_2O_7, and by others to be an "ozonide" of nitrogen. Whatever the true composition may be, the gas shows a spectrum which can be traced if the tube containing it be sufficiently long, and it so readily parts with its oxygen that it appears to be an oxidising agent far more powerful than any oxide of nitrogen or than ozone itself. It is, I believe, the presence of these extremely active bodies which accounts for the destructive action illustrated by the authors, and for the action on various varnishes sometimes described as superoxidation. This effect takes place more rapidly in damp air than in dry air, so that one of the conditions for successful insulation is dryness of the air—this is far more

important than any effect of change in specific inductive capacity brought about by the pressure of moisture. The authors have called attention to the value of paraffin wax as an insulating medium not easily affected. There is no doubt that certain varnishes made up from paraffin wax—as, for instance, "armalac"—are very satisfactory, but I have found, provided the discharge be sufficiently intense, that paraffin wax, like the other materials, breaks down and becomes a greenish-white powder. There is one other important point which has been omitted by the authors. I refer to the question of "frequency." Prepognot has shown that the quantity of ozone produced increases almost proportionately with the frequency, and I should therefore expect greater insulation difficulties with high-frequency machines. May I suggest also that where the presence of nitrous acid or nitrites is suspected a valuable and very delicate test, very easily applicable, may be found in the use of the so-called "Griess" reagent. Mr. Cramp.

Mr. H. D. SYMONS: I have been very interested in this paper, having had the opportunity of inspecting several machines where failure has been undoubtedly due to chemical action. The first case was that of a 2-phase, 7,500-volt generator, with one end of each phase grounded, and exactly the same phenomena with regard to the destruction of the insulation, as are described by the authors on pages 534 and 535, were observed. Previous to this I had always considered that the failure of machines experienced by Mr. Highfield, and attributed to the formation of nitric acid, had been due to either careless varnish treatment or the use of unsuitable insulating varnish. An examination of this machine, however, made it evident that something quite extraordinary had occurred in this case; a portion of one of the coils taken from the machine is exhibited on the table, from which it will be seen how marked the corrosion is. The sample also clearly shows the difference between the corrosion on the slot portion, due to chemical action, and the corrosion on the end of the coils, due to the use of a linseed oil varnish. The coils were former-wound and insulated with paper mica tubes, and the machine had failed by reason of a short circuit between turns in one phase. The coils of the phase in which breakdown had occurred on the whole fitted the tubes rather loosely, and the destruction of the insulation and corrosion of the copper were more marked than in the other phase. Analysis of the rotted insulation and copper corrosion proved the presence of nitric acid, and a number of samples of insulation removed from various portions of the coils showed a much more marked acidity on the slot portion of the coils. Samples from the slot portion of the higher voltage coils, where corrosion was most marked, had a higher acidity than samples from the low-voltage coils. In view of these facts it seemed desirable to obtain this corrosion experimentally, and a number of coils were made, insulated in different ways, and run at 6,600 volts for long periods of time. Breakdowns commenced after six months, and periodically occurred at different intervals of time on different coils; some have now run for nearly four years and are still standing up perfectly well. As each breakdown occurred the coils were Mr. Symons.

Mr. Symons. carefully examined, and it was interesting to note how the destruction of the insulation increased as the length of time of test increased. The deterioration of the insulation was quite gradual and resembled exactly the deterioration described by the authors on pages 531 to 534. Breakdown was always due to the heating of the dielectric by the discharge, since the coils were run from a transformer, the voltage being applied between the conductors and an outside metal wrap. Some of the coils that have broken down are exhibited on the table, and attention is drawn to the corrosion of the metal wrap in cases where this is copper. The authors state on page 535 that they do not consider the chemical action is in any way helped by the presence of copper, but this is quite contrary to the experience I have had with some coils made up with iron wires. Once the insulation commences to get tacky, its close proximity to the copper renders the formation of a copper salt easily possible; this commenced, short circuit between conductors must soon occur, for the deliquescent nature of the salt will cause the formation to spread rapidly. A bare tinned copper wire used as a lead on the high-tension side of a testing transformer showed no signs of corrosion in fifteen months, whereas a bare copper wire was badly corroded with copper nitrate in three months. Referring to Fig. 14, with regard to the use of a metal sheath around the conductors and the outside of the insulation, it is obviously difficult to accomplish this with sheet metal; indeed, it is extremely doubtful whether corrosion of the metal so used could be prevented. In connection with the experiments I have mentioned, a method of preventing corrosion by this means has been tried and proved quite successful. I made up a series of coils, giving the varnished cotton covering the conductors, the inside, and the outside of the insulating tubes a coat of aluminium powder such as is used for aluminium paints. These have been run at 6,600 volts in the same way, and whilst some of them have broken down the average life of the coils has been greatly increased; a few have now been running nearly two years, and it will be seen from the coils so treated, exhibited on the table, that there is neither any destruction of the insulation nor corrosion of the copper. Analysis shows no signs of the presence of nitric acid. In high-speed machines, or machines where the ventilation was at all violent, the aluminium powder might be objectionable, but by a careful method of applying it this difficulty could be overcome.

Mr. Hunter. Mr. P. V. HUNTER (*communicated*): I am afraid I can contribute very little towards carrying the good work of the authors any further, as the various supply companies in this district have never experienced any trouble due to chemical action in the windings of high-tension machines. The only interesting chemical effect of which I have any record occurred in some tubular floor insulator bolts for a 20,000-volt and 6,000-volt working. The insulators were grouted in the floor, projecting several inches on each side. The bolts were slightly longer than the insulator and a loose fit in it, with washers and nuts at each end to keep it in position. The bolts were of Muntz metal having

the following percentage composition: Copper, 57·76; lead, 2·22; zinc, 39·7; arsenic, 0·05. Shortly after a few of these bolts were put into commission one of them fractured inside the insulator and the bottom portion fell away. On examination the bolt was found to have a greyish-green deposit on it, and was full of longitudinal fissures extending sometimes for practically the whole length of the bolt and radially towards the centre; or occasionally the fissure, after travelling from the outside some distance towards the centre of the bolt, would change its direction and travel circumferentially. The effect was extremely remarkable in appearance and reminded one more of a piece of bamboo which had been pounded with a hammer so as to produce longitudinal cracks in it. The matter was submitted to the National Physical Laboratory, and in the report furnished by the Laboratory, the cause of the trouble was attributed to the lead in the composition of the bolt. This tends to make the Muntz metal brittle when hot, so that, in rolling the insulator bolts, fine rolling cracks are formed. These could be seen under the microscope in bolts which had never been used, although to the eye they were perfectly sound and homogeneous. The development of the cracks was due to the potential giving rise to the formation of oxides of nitrogen and nitric acid fumes in the practically closed space between the bolt and the inside of the insulator. These fumes readily penetrated the fine rolling cracks and caused the formation of basic nitrates within the cracks. The formation of the latter is accompanied by a considerable increase in volume, which would ultimately cause the cracks to widen and produce the complete fissuring of the bolts experienced, the whole action being similar to the manner in which frost bursts rocks or other material into which water has percolated. In reference to the arrangement of windings shown in Figs. 6 to 11, I may say that I have a very strong preference for one conductor per slot, particularly in the stators of 3-phase generators, and where it is necessary to transform I feel strongly that the generator pressure should be so fixed that this type of winding can be obtained. It is, perhaps, needless to point out, that with one conductor per slot it is possible to insulate the conductor in a very sound and homogeneous manner excluding all air. Mr. Hunter.

Mr. J. S. HIGHFIELD (*communicated*): I am particularly interested in the work the authors have done in tracing the action of nitrous oxides on organic matter. All the coils I have recently used for large alternators are wholly insulated with mica and a filling compound. As the authors state, it is not possible to fill in every air-space, owing to the contraction of the materials used when cooling. Where small spaces are left, I have found a slight amount of deposit, but, at the same time, this seems to reach a limit, and I have had no difficulty from this cause for several years. I am inclined to believe that a pressure of 10,000 volts to earth is quite the maximum pressure at which it is commercially sound to wind high-tension alternators, and then only when of large size. It is Mr. Highfield.

Mr. Highfield.

impossible to make the factor of safety as high for high pressures as for low pressures, and I rather think that coils should be wound for so high a pressure only in the case of slow-speed alternators, and that turbine alternators should not be wound for such high pressures unless much larger factors of safety can be obtained than what I know of at present. In the case of the failure of the insulation in a turbine alternator, particularly where end shields are used so as to enclose the whole machine, according to my experience, complete destruction of the winding takes place; that is to say, in the case of a burn-out the insulation is so damaged that every coil has to be re-insulated: whereas, with slow-speed alternators, only one or two coils are damaged and the repairs can be carried out in a day or two. In the case of a turbine alternator the repairs take as many months; with the large size units now being installed, the long period required for re-construction involves the use of a very large percentage, of spare plant. I do not know what factor of safety can be obtained in 10,000-volt windings on a 5,000- or 10,000-k.w. machine, but I am certainly inclined to think that for machines of 3,000-k.w. and under, the maximum pressure to earth should not exceed, say, 5,000 volts. In the long run, it is cheaper to wind the alternators for a low pressure, and use step-up transformers. I am glad to note that the authors have called attention to the green discoloration occurring with certain classes of varnish; as they say, this appears to be quite harmless.

Mr Turner.

Mr. H. W. TURNER (*communicated*): I am inclined to think that cause and effect have often been confused when dealing with insulation breakdowns. As an example, ozone, nitric acid-and sulphuric acid —due to the presence of moisture and cellular air-spaces in the windings—may have been caused by a prolonged excessively high potential test on the machine before it left the works and was put into regular service. Had the machine been warmed up on the test-bed and given a good long overload test so that all moisture might be driven out, and the pores then filled up while the machine was very hot, with a good non-volatile, air-drying varnish and allowed to cool before applying the flash test, there would be fewer insulation troubles after many years of service such as we now hear of. On page 535 the authors state that "certain varnishes produce a slight green organic deposit on copper." I have often observed this effect, but think that varnishes are too often blamed, when the fault has been in very many cases due to the presence of moisture in the fibrous materials, which was not extracted before the varnish was applied. On page 550 the authors' experience confirms my own *re* harmlessness of this green discoloration. It is a most deplorable fact that drying and baking facilities are seldom intelligently provided and maintained. Many so-called ovens either have too low or irregular temperature, or else put more moisture into the goods than they extract. On page 549 the authors state that "untreated cotton covering and other cellulose materials are generally excluded from machine windings for any voltage." I must disagree on this point, as my experience proves quite the reverse;

Mr. Turner.

although the engineers in charge generally admit the sound logic when the question is brought up, yet they seldom interfere with shop production. The winding department generally has to make up all the lost time in various other departments in the works, so that speed becomes of paramount importance and repair shops reap the benefits therefrom. In conclusion, I will say that I believe that with perfect impregnation of all cotton-covered wires, while hot, with cold non-volatile black varnishes before the wires are wound up into coils of any sort, the abolition of all hard fibrous materials that make varnish impregnation uncertain and very un-uniform, and above all, the elimination of cellular air-spaces in the windings and insulating materials, will result in there being no further necessity for discussions on chemical action in the windings of electrical machinery.

Messrs. Fleming & Johnson.

Messrs. A. P. M. FLEMING and R. JOHNSON (*in reply*): In reply to Mr. Beaver, we have to express our appreciation of his lucid explanation of the oxidation process of linseed oil. In regard to the desirability of thoroughly drying linseed oil varnishes, we are in entire agreement as to the importance of this, but find that in practice it is a result almost impossible to achieve except under extremely prolonged drying. A film readily forms on the surface, which retards the oxidation of the varnish underneath; at the same time the film to some extent protects the varnish from the oxidising effects of ozone or other products of the air-gap discharge. We note his comments as to certain advantages of the use of varnishes over that of solid impregnating compounds and the difficulty of obtaining good penetration with the latter. We are in agreement with his views in cases where a treatment, as distinct from a filling, is required and when chemical action resulting from high-voltage stresses is not to be feared. Regarding the use of metal foil to prevent air-gap discharge, since writing the paper the authors have heard of one or two machines in which the arrangement shown in Fig. 14 has been applied. Mr. Miles Walker's explanation of the heating of insulation due to the internal loss is most interesting. Concerning the question of temperature, we would say that the figure of 35 volts per mil for the average stress in the slot insulation is safe for machines at their maximum working temperature. As regards his suggestion that for high voltages the thickness of dielectric must be increased more than in proportion to the voltage on account of the rapid increase in dielectric loss (which consequently tends to cause failure due to the heating thus set up in the insulation), we would point out that with the materials used and for voltages up to the maximum at present employed, the thickness of insulation required to prevent chemical action is more than sufficient to meet the voltage requirements. It is only where the stress is forced much higher than 35 volts per mil that this feature has to be taken into account. In addition to the effect of the temperature on the insulation value as mentioned by Mr. Walker, we would point out that the rapidity of the chemical action is influenced by the same factor. In reply to Mr. Cramp, we would say that the paper has reference to

Messrs. Fleming & Johnson.

alternating-current pressures only. It was not thought necessary to make any investigations into the effects of high direct-current pressures, since at the present time there is no commercial application for them in this country. In the high-voltage direct-current series systems at present in operation on the Continent, the actual electrostatic stress between conductors and frame on the machines is comparatively low, when the machine frames are well insulated from ground. We note his remarks in regard to the destructive action of some of the higher oxides of nitrogen which are probably present when discharge takes place. This confirms the authors' view that the destruction of the insulation originates from the oxidising effects of the gases produced by the discharge, and is not due to any direct action of nitric acid even when this is formed. We agree with Mr. Cramp that frequency is an important factor, but only in so far as it governs the rapidity of action. We do not, of course, suggest that there is any advantage to be gained by the use of damp paper in insulation in order to obtain the benefit of improved specific conductive capacity.

Mr. Symons has misread the paper when he states that the authors "do not consider the chemical action is any way helped by the presence of the copper"; the sentence referred to reads, "that the presence of the copper had no direct influence on the deterioration of the insulation." The action of copper nitrate in causing short circuits has been fully dealt with elsewhere in the paper. In regard to the tests carried out on sample coils in which a high voltage was maintained between the assembled conductors and a layer of foil around the outside of the insulation, additional interest would have been lent to the tests if the deterioration in the insulation had been ascertained at the most vital point by applying periodic voltage tests between adjacent turns. So far as the use of aluminium paint is concerned, the risk of sparking or heating due to imperfect conductivity offers a serious objection. Mr. Highfield's experience agrees with our own inasmuch as it is impossible to obtain perfectly solid coils. It is specially interesting to note that coils in the machines with which he has had so much experience were mica-insulated, and that although some action occurred in the small air-spaces which existed, this was presumably on the organic cements used for building up the mica, and the extent of the action was very slight. With regard to the maximum voltage to ground for which machines can be wound, this depends on two factors, namely, that the conductors must be of such a number and size that a coil of sound construction free from internal weaknesses can be obtained, and that sufficient radial thickness of insulation is used. For machines under about 1,000 k.w. his figure of 10,000 volts to ground as the maximum limit is probably about right. For larger sizes we are of opinion that it is possible to push the voltage much higher without incurring risks due to chemical action. This question, however, involves financial considerations such as were dealt with to some extent by Mr. Behrend in his paper read some two or three years ago before the

American Institute of Electrical Engineers, in which he advocated the use of 22,000-volt generators.* It might be noted also that machines of this and higher voltages have from time to time been constructed and are operating satisfactorily. We are in general agreement with Mr. Highfield's comments, in comparing turbo-alternators with engine-type generators, regarding the ease with which the windings of the latter can be repaired. Mr. Hunter mentioned an interesting instance of chemical action in the case of a floor insulator; we have met with similar examples of this action. In reply to Mr. Turner, we are unable to agree that severe pressure tests in the manufacturing works are ever likely to cause failure of machines by the formation of ozone or nitric acid, although, as pointed out in the paper, such tests may cause other damage to the insulation. Pressure tests are rarely applied for periods exceeding one hour, whereas, even under extreme conditions, some months generally elapse before actual failure due to chemical action occurs. We are of opinion that varnish cannot be used satisfactorily to overcome chemical action in high-voltage windings and have given our reasons on page 544 of the paper. We accept Mr. Turner's suggestion that untreated cellulose materials are sometimes used on machines, but are inclined to believe that this practice is confined almost entirely to very low voltages. Messrs. Fleming & Johnson.

* *Transactions of the American Institute of Electrical Engineers*, vol. 26, p. 351, 1907.

THE NON-SALIENT POLE TURBO-ALTERNATOR AND ITS CHARACTERISTICS.

By STANLEY P. SMITH, M.Sc., Associate Member.

Paper received December 29, 1910. *Read before the* BIRMINGHAM LOCAL SECTION *March* 8, 1911.)

The demand in recent years for large units running at high speeds has led to the introduction and development of a new type of turbo-alternator. The essential feature of this new type is the substitution of the non-salient pole or cylindrical rotor for the ordinary salient pole rotor as used with slow-speed alternators. The many advantages of this type of rotor compared with the salient pole type need not be discussed here ; it is quite sufficient to mention that they have proved sufficient to induce many—I might almost say most—of the leading firms, both in this country and abroad, to adopt this construction. Moreover, the mechanical details of the non-salient pole rotor need not interest us here, except indirectly, the sole object of this paper being an investigation into its electrical characteristics, including the shape of the M.M.F. and flux curves and the consequent pressure waves. With respect to these latter it will be seen that the non-salient pole alternator closely approaches the ideal machine.

Fortunately at the outset of the paper there is no need to enter into a discussion of the relative merits of the different forms of pressure wave. Though at one time there was a good deal of discussion as to the best wave shape, this question is practically settled nowadays, and the general opinion is overwhelmingly in favour of the simple sine curve. Without entering into arguments to show why such a wave seems to be both the theoretical and practical ideal for alternating-current working, it may not be out of place to mention a few of the main reasons why this is so. In the first place, the true sine wave is the simplest periodic function possible, and forms the fundamental in any complex curve, whilst the remainder is composed of harmonics superposed on this. Secondly, this ideal curve at once settles the question of a standard. Thirdly, the power factor and efficiency of a system are generally better with a sine wave than with any other. Fourthly, experience has proved that pure sine waves are less subject to alteration under varying conditions of load than complex waves. Fifthly, instruments affected by wave shape can be made independent of this if a sine wave is used both for calibration and working. Lastly, it must not be forgotten that most of our alternate-current theory is based

on the assumption of a simple sine wave and only holds so long as this condition is fulfilled. There is no need to go into the effects arising from distorted waves, nor the influence they have on parallel working, resonance, and so on, as these matters are quite general and have no particular bearing on the present paper.

It will presently be seen how nearly the non-salient pole turbo-alternator possesses this ideal characteristic as an inherent property arising from the shape of its M.M.F. and flux wave. Thus its wave shape is not mainly dependent on the disposition of the armature winding and the interlinking of the phases, which is generally the case with the 3-phase salient pole alternator.

The great advantage of this inherent property of the non-salient pole machine lies in the fact that the flux curve retains practically the same shape on load as on no load, in consequence of which the shape of the wave of terminal pressure suffers minimum distortion.

For the sake of convenience, the paper will be divided into the following sections:—

1. The non-salient pole alternator.
2. The M.M.F. curve and its analysis.
3. The flux curve.
4. Synthesis of flux and pressure curves. Calculation of open-circuit characteristic.
5. Effect of load.
6. Standardisation.

In addition to the above there is also the effect of the teeth, which may become important unless means are used to suppress the pulsations thus set up. It will be advisable, however, to leave over the consideration of this, along with other matters, for a future paper, where they may be adequately discussed.

1. *The Non-salient Pole Alternator.*—Compared with a salient pole machine, the calculation of the flux distribution in the gap of a non-salient pole machine is a simple matter. In Fig. 1 is shown a salient pole with its flux curve. It will be recalled that the determination of the shape of this curve involves a considerable amount of troublesome guess-work on account of the tubes of force having to be drawn out and estimated. Even then several repetitions have to be made before a reasonable mean can be obtained.

Turning to the cylindrical rotor, however, which has usually two or four poles, it is much easier to predict what the flux curve will be like, and it is by no means difficult to obtain results in accordance with actual oscillograms, if only the necessary knowledge of the permeability of the iron, etc., is available.

In Fig. 2 is shown a simple bipolar rotor of the non-salient pole type. As this forms a fair sample of an actual rotor, it may be considered further before passing on to the more general case. There are 32 slots on the rotor circumference. These slots are uniformly spaced, and in them is placed the exciting winding. Of the 16 slots per pole

only 12 are wound, and the middle four, forming the centre of the pole, are left empty. Thus there are 12 slots wound out of 16, which I shall hereafter refer to as a $\frac{12}{16}$ or $\frac{3}{4}$ winding. Denoting this ratio

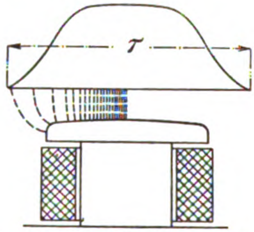


FIG. 1.—Example of Salient Pole and its Flux Curve.

by β, we may have, for example, $\beta = \frac{12}{16}, \frac{14}{16}, \frac{10}{13}, \frac{12}{18}$, and so on. Further, in the above example, Fig. 2, it has been assumed that each wound slot contains the same number of conductors, and all the latter are in series.

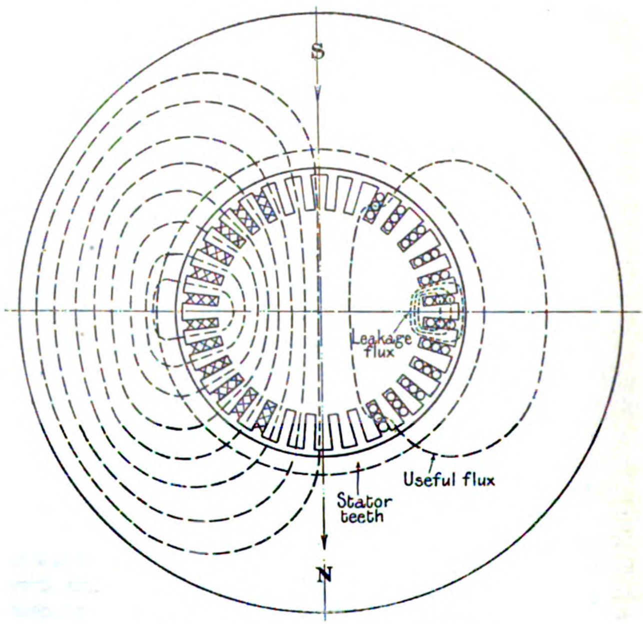


FIG. 2.—Non-salient Pole Machine.
2 poles, 16 slots per pole—12 wound, 4 empty.

The air-gap between rotor and stator is taken as constant over the whole periphery. This will form the simplest possible case of the non-salient pole rotor, the M.M.F. curve for which can be obtained straight away, and is shown in Fig. 3. The step curve is the actual

M.M.F., whilst the trapezium represents the mean M.M.F. curve. Thus the ratio β may be written $\beta = \frac{2\,L}{\tau}$.

Though the method of winding just described is that adopted by many of the largest firms, of course with varying values of β, yet there are several modifications found in practice. For example, the unwound part of the rotor may be left solid and only the wound part slotted. Again, different sized slots may be used at different parts of the circumference, and different numbers of conductors per slot employed. Also the slots, instead of being radial, may all be parallel to one another, and the middle of the pole left unslotted. Further, the air-gap may be varied over a pole-pitch, being least at the centre of the pole, and so on. All these modifications, however, can be considered as special cases of the general arrangement outlined in Fig. 2, and will not, therefore, be further dealt with in this paper.

Consequently I shall entirely devote my attention to the rotor slotted uniformly over the whole periphery, all the slots being of the

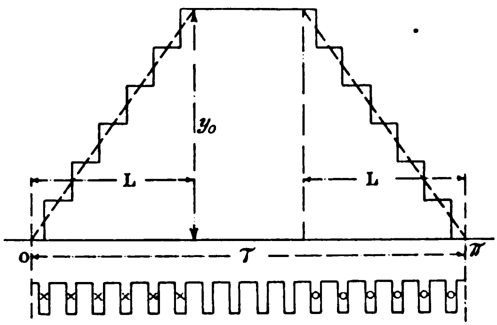


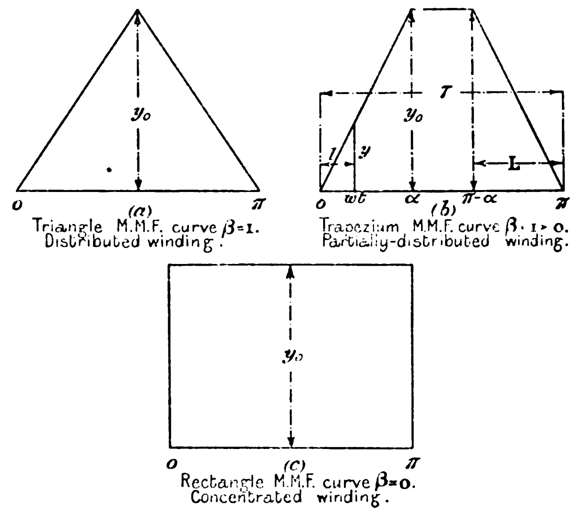
FIG. 3.—M.M.F. Curve of Rotor in Fig. 2.

same size, and all the wound slots containing the same number of conductors. Whether the rotor is made up of steel-plates, laminations, or out of a solid forging, is also immaterial to what follows, these being merely details of construction, and also the manner of ventilation—whether radial or axial or both—will not be considered in any way.

We now return, therefore, to the general arrangement in Fig. 2, and the corresponding M.M.F. curve in Fig. 3. At the outset no argument is needed to show that the flux curve must, in general, follow the M.M.F. curve, so that, provided no saturation is present in the magnetic circuit, the shape of the M.M.F. curve will also represent the shape of the flux curve. Thus the step curve of magnetomotive force in Fig. 3 will be the distribution of the flux in the gap to another scale, until saturation begins to make itself felt. The way in which the sharp corners of the step curve are actually rounded off in practice will be dealt with later. For the present we shall only consider the mean value of the step curve, viz., the trapezium. This simplification intro-

duces no appreciable error, and enables us to treat the problem without complication.

Now since the curve of E.M.F. induced in the armature winding contains the same harmonics as the flux curve, though reduced in proportion to their respective winding factors (see section 5), it at once follows that the nearer the latter approaches a sine wave the more nearly sinusoidal will be the shape of the pressure curve. Further, until the flux curve begins to be affected by saturation, it will be practically identical with the M.M.F. curve. Thus it becomes of importance to know how and to what extent the M.M.F. curve differs from a sine wave. This leads us at once to consider the shape of the M.M.F. curve.



(a) Triangle M.M.F. curve $\beta = 1$. Distributed winding.

(b) Trapezium M.M.F. curve $\beta < 1 > 0$. Partially-distributed winding.

(c) Rectangle M.M.F. curve $\beta = 0$. Concentrated winding.

FIG. 4.

2. *The M.M.F. Curve and its Analysis.*—We proceed, therefore, to consider the effect of the ratio—

$$\beta = \frac{\text{wound part of pole-pitch}}{\text{whole pole-pitch}} = \frac{2\,L}{\tau}$$

on the composition of the M.M.F. curve, and then pass on to see how the flux curve is affected by saturation. In Fig. 4 the extreme values of β are shown in Diagrams (*a*) and (*c*), the triangle and rectangle respectively, whilst the general case, viz., the trapezium, is shown in Diagram (*b*). The triangle—Diagram (*a*)—represents a winding distributed uniformly over the whole periphery ; the trapezium—Diagram (*b*) —over a certain fraction of the periphery ; and the rectangle—Diagram (*c*)—concentrated in one slot per pole. The last case is really only of theoretical interest. The same maximum magnetomotive force or exciting ampere-turns y_0 is assumed in each case.

It is at once seen how much more readily the non-salient pole rotor lends itself to the calculation of the distribution of the M.M.F. and flux than the salient pole type, for all that is now required is to take the general case, viz., the trapezium, and investigate its harmonics by means of Fourier's theorem. This, of course, is done analytically.

For a curve symmetrical with respect to the abscissa axis and the negative part the image of the positive, Fourier's series can be written—

$$\begin{aligned} f(x) &= a_1 \sin x + a_3 \sin 3x + \ldots a_n \sin n x + \ldots \\ &\quad + b_1 \cos x + b_3 \cos 3x + \ldots b_n \cos n x + \ldots \end{aligned}$$

To find the amplitudes a_n it is only necessary to multiply each side by $\sin m x$ and integrate between 0 and 2π. The terms thus obtained will be of the form—

$$\int_0^{2\pi} a_n \sin n x \sin m x \, d x \quad \text{and} \quad \int_0^{2\pi} b_n \cos n x \sin m x \, d x.$$

Solving these integrals, all terms vanish except the former for the case $m = n > 0$, which gives—

$$\int_0^{2\pi} \sin^2 n x \, d x = \pi,$$

so that—

$$\int_0^{2\pi} f(x) \sin n x \, d x = \int_0^{2\pi} a_n \sin^2 n x \, d x = a_n \pi,$$

whence—

$$a_n = \frac{1}{\pi} \int_0^{2\pi} f(x) \sin n x \, d x.$$

Similarly to find b_n we multiply all through by $\cos m x$ and integrate between the limits 0 and 2π, whence—

$$b_n = \frac{1}{\pi} \int_0^{2\pi} f(x) \cos n x \, d x.$$

Again, in a curve symmetrical about the abscissa axis possessing only odd harmonics—

$$\sin n x = - \sin n (x + \pi),$$

so that—

$$\begin{aligned} a_n &= \frac{1}{\pi} \int_0^{2\pi} f(x) \sin n x \, d x \\ &= \frac{2}{\pi} \int_0^{\pi} f(x) \sin n x \, d x. \end{aligned}$$

To analyse the curves in Fig. 4, we start with the general case, the trapezium.

Analysis of the Trapezium Curve of M.M.F.—The equation of this

curve, Fig. 4 (*b*), is $y = f(\omega t)$, where ωt represents the angle x. It will be seen that the curve is made up of three parts—

1. From o to a; $y = y_0 \frac{\omega t}{a}$.
2. From a to $\pi - a$; $y = y_0$.
3. From $\pi - a$ to π is similar to (1).

Then—

$$a_n = \frac{2}{\pi}\int_0^\pi y \sin n\omega t \, d(\omega t)$$

$$= 2 \times \frac{2}{\pi}\int_0^a y_0 \frac{\omega t}{a} \sin n\omega t \, d(\omega t) + \frac{2}{\pi}\int_a^{\pi - a} y_0 \sin n\omega t \, d(\omega t)$$

$$= \frac{4 y_0}{\pi a n^2}\int_0^a n\omega t \sin n\omega t \, d(n\omega t) + \frac{2 y_0}{\pi n}\int_a^{\pi - a} \sin n\omega t \, d(n\omega t)$$

$$= \frac{4 y_0}{\pi a n^2}\Big\{ - n\omega t \cos n\omega t + \sin n\omega t \Big\}_0^a - \frac{2 y_0}{\pi n}\Big\{ \cos n\omega t \Big\}_a^{\pi - a}$$

$$= \frac{4 y_0}{\pi a n^2}(-n a \cos n a + \sin n a) + \frac{2 y_0}{\pi n} 2 \cos n a$$

$$= \frac{4 y_0}{\pi a}\frac{1}{n^2} \sin n a.$$

But the angle π represents the pole-pitch τ, similarly the angle a can be represented in length by L, whence we get—

$$\frac{a}{\pi} = \frac{L}{\tau} \quad \text{or} \quad a = \frac{L}{\tau}\pi.$$

Substituting for a in the expression for a_n, we get—

$$a_n = \frac{4 y_0}{\pi a}\frac{1}{n^2} \sin n a$$

$$= \frac{4 y_0 \tau}{\pi L . \pi n^2} \sin n \frac{L}{\tau}\pi$$

$$= \frac{8 y_0}{\pi^2}\frac{\tau}{2 L}\frac{1}{n^2} \sin n \frac{2 L}{\tau}\frac{\pi}{2}$$

$$= \frac{8 y_0}{\pi^2 \beta}\frac{1}{n^2} \sin n\beta \frac{\pi}{2},$$

where—

$$\beta = \frac{2 L}{\tau} = \frac{\text{wound part of } \tau}{\tau}$$

Since the curve is symmetrical about the $\frac{\pi}{2}$ axis, there are no cosine terms, hence $b_n = 0$.

Consequently the general expression for the *trapezium* is—

$$y = \frac{8 y_0}{\pi^2 \beta}\Big(\sin\beta\frac{\pi}{2}\sin\omega t + \frac{1}{9}\sin\beta\frac{3\pi}{2}\sin 3\omega t + \frac{1}{25}\sin\beta\frac{5\pi}{2}\sin 5\omega t + \dots\Big).$$

From this equation we are now able to find the harmonics for any given value of β.

Take for example, $\beta = 1$. This is the *triangular* curve, and we have—

$$y = \frac{8\,y_0}{\pi^2}\left(\sin\frac{\pi}{2}\sin\omega t + \frac{1}{9}\sin\frac{3\,\pi}{2}\sin 3\,\omega t + \ldots\right)$$
$$= \frac{8\,y_0}{\pi^2}\left(\sin\omega t - \frac{1}{9}\sin 3\,\omega t + \frac{1}{25}\sin 5\,\omega t - + \ldots\right).$$

For this and the other values of $\beta = 0{\cdot}9$, $0{\cdot}8 \ldots 0{\cdot}1$, all the harmonics up to the 11th have been worked out and tabulated (see Table I.).

To find the harmonics of the *rectangle* we cannot evaluate β as above, since, by doing so, we obtain indeterminate quantities.

For the curve, Fig. 4, *c*, therefore, we have—

$$a_n = \frac{2}{\pi}\int_0^{\pi} y\sin n\,\omega\,t\,d\,(\omega\,t).$$
$$= \frac{2}{\pi}\frac{y_0}{n}\int_0^{\pi}\sin n\,\omega\,t\,d\,(n\,\omega\,t) \quad \text{since } y = y_0.$$
$$= -\frac{2}{\pi}\frac{y_0}{n}(\cos n\,\pi - \cos 0).$$
$$= \frac{4}{\pi}\frac{y_0}{n}.$$

Hence for the *rectangle* we have—

$$y = \frac{4}{\pi}y_0\left(\sin\omega t + \frac{1}{3}\sin 3\,\omega t + \frac{1}{5}\sin 5\,\omega t + \ldots\right).$$

It is interesting to compare the amplitudes of the fundamentals in the extreme cases of the triangle and rectangle.

Thus—

$$\frac{\text{Amplitude of fundamental of rectangle}}{\text{Amplitude of fundamental of triangle}} = \frac{\frac{4}{\pi}}{\frac{8}{\pi^2}} = \frac{\pi}{2}.$$

Table I., giving the harmonics for different values of β, is very instructive, and to obtain a clearer insight into the way the several harmonics in the M.M.F. curve depend on the distribution of the exciting winding, the percentages given in this table have been plotted as a function of β in Fig. 5. Only harmonics up to the 7th have been plotted, as beyond this they become negligibly small for practical values of β. The absolute value of the fundamental in terms of y_0 is also reproduced in Fig. 5.

Since, moreover, it is the fundamental that interests us chiefly, as what we have to strive after is a sine wave flux or E.M.F. curve, the diagrams in Fig. 6 have been drawn to show this harmonic, together

TABLE I.

Showing the Values of the Harmonics in the Trapezium Curve of M.M.F. for different Values of β.

$\beta = \frac{2L}{\tau}$.	Constant $\times y_0$.	Harmonics in per Cent.					
		1.	3.	5.	7.	9.	11.
1·0 (triangle)	0·810	100	−11·1	4·0	− 2·0	1·2	−0·8
0·9	0·890	100	−10·0	2·9	− 0·9	0·2	0·1
0·8	0·960	100	− 6·9	—	1·3	− 1·2	0·8
0·7	1·030	100	− 1·9	− 3·2	2·3	− 0·6	−0·4
0·6	1·095	100	4·3	− 4·9	0·8	1·2	−0·8
0·5	1·150	100	11·1	− 4·0	− 2·0	1·2	0·8
0·4	1·190	100	18·0	—	− 3·5	− 1·2	0·8
0·3	1·220	100	24·2	6·2	− 0·7	− 2·4	−1·6
0·2	1·250	100	29·2	12·9	5·3	1·2	−0·8
0·1	1·260	100	32·4	18·1	11·7	7·8	5·2
0·0 (rectangle)	1·270	100	33·3	20·0	14·3	11·1	9·1

TABLE II.

Showing how Output is Increased with Constant M.M.F. by Concentrating the Exciting Winding.

Value of β.	Output of Machine.
	Per Cent.
1·0	100·0
0·9	110·0
0·8	118·5
0·7	127·0
0·6	135·0

with its respective trapezium curve of M.M.F. These diagrams have been drawn for practical cases lying within the range $\beta = 1{\cdot}0$ and $0{\cdot}6$ (see later), and the limiting case of the rectangle. y_0 is assumed constant throughout.

3. *The Flux Curve:* A. *Without Saturation.*—The above information with respect to the composition of the M.M.F. curve now enables us to discuss the flux curves in machines where no saturation is present, since in this case these two curves are identical in shape. Now, the first question that naturally occurs is the distribution of the exciting winding, or, in other words, the value of β. When determining the

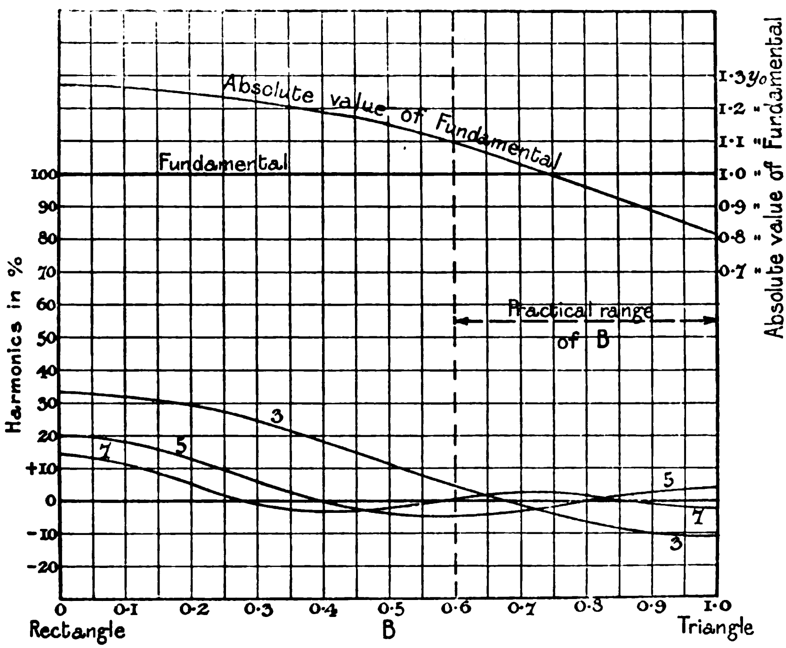


FIG. 5.—Harmonics in M.M.F. Trapezium for different Values of β.

best value of β both the magnetic (or electric) and the mechanical relations must be discussed.

First, we will consider the electrical relations. Table I. and Figs. 5 and 6 show that the more we concentrate the winding, the greater is the amplitude of the fundamental of the M.M.F. or flux curve (since a non-saturated machine is assumed) for a given maximum M.M.F. y_0. At first sight this might appear to be solely advantageous, since the greater the flux the higher the E.M.F., and therefore the larger the output of the machine. On the other hand, however, it must not be forgotten that this larger flux has to be accommodated, and extra surface must be allowed if the flux densities are not to increase. Thus,

by concentrating the exciting winding, a larger machine may be required for the increased output. If, however, an increased flux or output is not required, then it is clear that a given amplitude of the fundamental can be obtained from fewer ampere-turns with a concentrated winding than with a distributed winding. To illustrate this argument, Tables II. and III. are given to show the increase of output

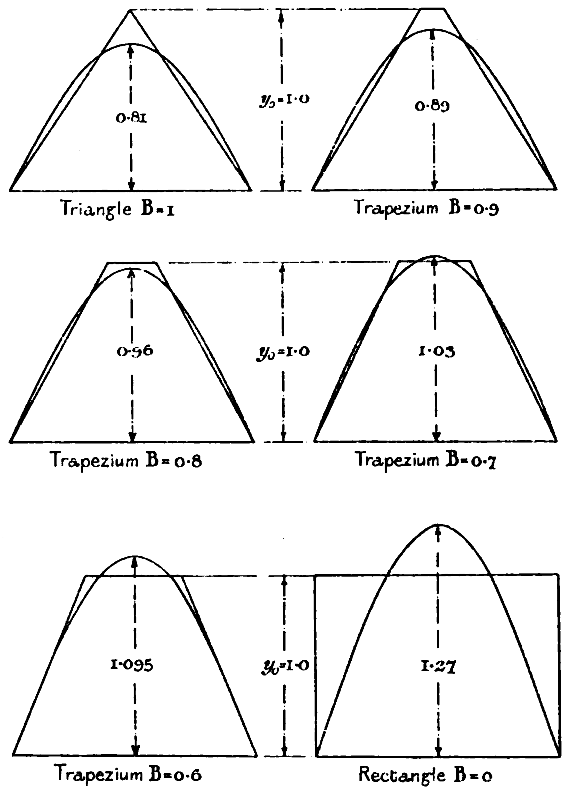


FIG. 6.—M.M.F. Curves for different Values of $\beta = \frac{2L}{\tau}$ and their Fundamentals.

or decrease in ampere-turns due to concentrating the winding. Since in practice β is seldom made less than 0·6, we shall not go below this value.

In Table II. the output of the machine with a uniformly distributed winding ($\beta = 1$) is taken as 100 per cent. As mentioned above, the increase in output thus obtained is due to the increased flux or E.M.F., the armature current or reaction remaining constant. Actually, however, the larger flux will require an increased section, so

that to obtain these higher outputs it will be necessary to modify the design of the machine accordingly, or eventually to increase its size.

Table III. is still more instructive, as it shows how the necessary ampere-turns for a given flux are reduced, as the winding becomes more concentrated.

TABLE III.

Showing how M.M.F. is Decreased with Constant Output by Concentrating the Winding.

Value of β.	Required M.M.F. or Exciting Ampere-turns.	Decrease in Excitation or Copper.
	Per Cent.	Per Cent.
1·0	100·0	0·0
0·9	91·0	9·0
0·8	84·5	15·5
0·7	78·5	21·5
0·6	74·0	26·0

From this it is seen what an enormous saving in excitation is made when the winding is concentrated. As an offset against this, however, is the difficulty of accommodating the winding in the slots when concentrated, which we shall presently discuss.

TABLE IV.

Showing how Harmonics vary from $\beta = 1·0$ *to* $\beta = 0·6$.
(*Fundamental* = 100 *per cent.*)

Value of β.	3rd Harmonic.	5th Harmonic.
	Per Cent.	
1·0	−11·1	4·0
0·9	−10·0	2·9
0·8	− 6·9	—
0·7	− 1·9	−3·2
0·6	4·3	−4·9

The general tendency of Tables II. and III., however, is to show that it is advantageous not to have the winding too distributed, but there are other points to be considered before final conclusions can be arrived at.

At the same time, it may be well to recall here that the output of a turbo-alternator is chiefly governed by the output of the rotor, so that it becomes of the highest importance to make this a maximum.

The next point is to consider the higher harmonics and to see how these depend on the distribution of the exciting winding. These harmonics are given in Table I. and shown graphically in Fig. 5. If we go over the whole range, from the triangle to the rectangle, it is seen that as the winding becomes more concentrated the harmonics increase in value along with the fundamental. Over the practical range, however, the higher harmonics, except the 3rd, do not vary very much, as seen from Table IV.

All harmonics above the 5th are negligible: firstly because their magnitude is very small, and secondly because their winding factors

TABLE V.

Winding Factors for Distributed Windings.

Winding Factor.	3-phase Winding.	2-phase Winding.
$f\omega_1$	0·956	0·901
$f\omega_3$	0·636	0·300
$f\omega_5$	0·191	−0·180
$f\omega_7$	−0·137	−0·129

are very low, so that they practically vanish altogether from the pressure wave.

With regard to the 3rd and 5th harmonics, these may reach 10 and 5 per cent. respectively of the fundamental in the flux wave as we pass from $\beta = 0{\cdot}9$ to $0{\cdot}6$, so that it is necessary to see what effect these can produce in the pressure wave. To examine this effect it is best to consider the winding factors of these harmonics. We need only consider a distributed stator winding, which practically covers all values of $q \geqq 4$, where q is the number of slots per pole and phase.

Taking the amplitude of the 3rd harmonic as 10 per cent., and of the 5th as 5 per cent. in the flux curve, the value of these harmonics in the pressure curve would be as shown in Table VI.

Thus we see that the maximum amplitude the 5th harmonic can attain in either a 2- or 3-phase machine is 1 per cent., but is generally much less than this. Hence the 5th harmonic in the pressure wave of a non-saturated machine can—along with all other harmonics of a still higher order—be neglected.

We are only left now with the 3rd harmonic. Except in the neighbourhood of $\beta = 0{\cdot}7$ (at $\beta = 0{\cdot}66$ the 3rd harmonic is zero) this harmonic becomes appreciable, and as we see may reach nearly 7 per

cent. in a 3-phase machine and over 3 per cent. in a 2-phase machine. Of course, in the former case, if the phases are interlinked and the neutral insulated, the harmonic will not appear in the wave of terminal pressure. Nevertheless, it will always be present inside the machine, and even if it cannot appear at the terminals it is associated with a flux whose amplitude is 10 per cent. of that of the fundamental. If β is chosen between 0·6 and 0·8, however, the amplitude of this harmonic will only be about half the above maxima, so that it is well to have the winding somewhat concentrated if this harmonic is to be kept small.

With respect to the higher harmonics, therefore, we see that only the third need be considered, and to make this small, β should be kept between 0·8 and 0·6. The values of β between 0·8 and 0·6, therefore, or, more strictly speaking, between 0·7 and 0·6, are the best for obtaining a sine wave flux and E.M.F. in a non-saturated machine.

The question of harmonics will be considered further when we come to deal with saturation.

The mechanical effect of varying β must now be considered. We have already seen that to obtain a curve approximating to a sine curve

TABLE VI.

Maximum Values of 3rd and 5th Harmonics between $\beta = 0·9$ and $\beta = 0·6$.

Harmonic.	3-phase.	2-phase.
	Per Cent.	Per Cent.
Fundamental	100·00	100·0
3rd	6·65	3·3
5th	1·00	1·0

we must not make $\beta < 0·6$. We shall see that for mechanical reasons also this becomes the limit. In the first place, we must remember that the lower we make β, the more concentrated becomes the exciting winding and the more limited the space to accommodate it. Of course, the natural expedient here is to make wider and deeper slots, but to both these dimensions there are limits. The larger the slots the greater the mechanical difficulties of securing the winding and obtaining the necessary strength in the teeth. Moreover, wide slots become troublesome on account of the tooth ripples. In addition to these difficulties there is the further one of cooling. With a distributed winding the heating is spread uniformly over the whole core, and the ventilation is equally effective all over. On the other hand, concentrating the winding over a limited area increases the amount of heat per slot which has to be dissipated, and thus makes ventilation more difficult. To overcome this it may be necessary to reduce the excitation loss by placing more copper in the slots, thus leading to

further unfavourable conditions. Again, in concentrating the winding care must be taken not to interfere with the balance of the rotor. Though theoretically this may be a matter of small moment, yet in practice it becomes all-important.

At the same time, however, we must not forget the advantages of having the winding concentrated somewhat. These advantages were emphasised in Tables II. and III. The latter table is especially instructive, and enables us to see how far we may reduce the M.M.F. required for a given flux without encountering serious difficulties. Thus we see that by making $\beta = 0{\cdot}9$ (that is, concentrating 10 per cent.) we only need 91 per cent. of the ampere turns and have 90 per cent. of the winding space at our disposal. Thus with $\beta = 0{\cdot}9$ the heating is reduced to 91 per cent., whilst 9 per cent. in copper is saved. Making $\beta = 0{\cdot}8$ we must now accommodate 84·5 per cent. of the exciting winding in 80 per cent. of the space, which means that the amount of copper or heating in the wound part is increased 6 per cent., whilst the total copper or loss is reduced 15·5 per cent. Of course, we are assuming a constant current density throughout.

In a similar way we see that with $\beta = 0{\cdot}7$, 78·5 per cent. of the copper must be wound over 70 per cent. of the whole pitch, an increase of about 11 per cent., which is not serious, and can be accommodated by suitably modifying the design. In this case the economy in copper is 21·5 per cent., whilst the heating in the wound part is increased 11 per cent., though the total is reduced 21·5 per cent. Lastly, $\beta = 0{\cdot}6$ brings us to the point where difficulties may be encountered, for we now have an increase of 21 per cent. to provide for in the heating and space required for the copper. Moreover, the saving in copper and total loss is now beginning to fall off rapidly, whilst it is certainly questionable whether the design can be altered so as to make such a machine quite satisfactory without using more active material.

The above figures are quite enough to show within what limits β should be chosen, and it is highly satisfactory to find that the distribution of the exciting winding which gives the requisite sine wave is also suitable from a mechanical standpoint, for these limits of β give a winding that considerably reduces the total loss and copper, whilst at the same time the heating and space required for copper in the wound part is only increased by an amount that leads to no constructional difficulties.

On the other hand, no advantage is gained either electrically or mechanically by distributing the winding over more than 90 per cent. of the periphery.

In conclusion, therefore, we may say that the best distribution of the winding from all points of view is obtained with the value of β between 0·85 and 0·65; that is to say, the exciting winding should extend over 65 to 85 per cent. of the circumference.

To give an idea of the values of β met with in practice we append below a few cases that have come under the author's notice:—

$$\beta = \tfrac{12}{18},\ \tfrac{10}{14}\ \tfrac{20}{28},\ \tfrac{8}{11},\ \tfrac{12}{16},\ \tfrac{10}{13},\ \tfrac{14}{17},\ \tfrac{10}{12},\ \tfrac{12}{14},\ \tfrac{14}{16},\ \tfrac{18}{20},\ 1{\cdot}0.$$
$$= 0{\cdot}66,\ 0{\cdot}71,\ 0{\cdot}73,\ 0{\cdot}75,\ 0{\cdot}77,\ 0{\cdot}825,\ 0{\cdot}835,\ 0{\cdot}85,\ 0{\cdot}87,\ 0{\cdot}9,\ 1{\cdot}0.$$

We will now pass on to consider how the above arguments are affected by saturation in the magnetic circuit.

B. *With Saturation.*—The object of saturation in a machine is to produce good regulation where no automatic means of adjusting the exciting current to maintain constant voltage are provided. It is thus necessary to work on the flat part of the magnetisation curve—*i.e.*, above the knee—when close regulation is required. In such cases it is usual to design the machine so that normal pressure at no load lies just beyond the knee of the magnetisation curve, so that as the load increases the excitation moves over the flat part of the curve.

Now, a little consideration will show that practically the only part of the magnetic circuit in a non-salient pole turbo-alternator that can be saturated is the rotor teeth. With regard to the cores, saturation of the stator core is, of course, out of the question, whilst the rotor core rarely attains high densities, except in bipolar machines, where, however, it is by no means rare. Also it is neither desirable nor practicable to work the stator teeth at high saturation. The rotor teeth in the cylindrical rotor, therefore, play the same part with respect to saturation as the salient poles in a slow-speed alternator.

But saturation in a machine can only be obtained at the expense of the exciting current (or loss), and since the output of the turbo-alternator is, in general, determined by the output of the rotor, it is at once obvious that for a given rotor and excitation loss, the higher the saturation the less will be the output of the machine. Hence when fine regulation is required, either the machine must be fairly large for its output or the output of the rotor must be forced by increasing the allowable temperature rise or improving the ventilation. On the other hand, if the question of regulation is not so important or an automatic regulator is used, then the designer can for the same output lower the flux—that is, decrease the saturation. In this way the exciting current can be made much smaller, whilst the armature pressure is maintained by increasing the number of turns on the stator. Since the exciting current, however, decreases much more rapidly than the flux, the armature reaction can now be made much larger before the same excitation loss is reached, and in this way the output of the machine can be raised.

The effect of saturation on the output of the machine is best illustrated in the last section of this paper.

Coming now to deal with the effect of saturation on the wave shape, it is not possible to discuss this in a quite general way, since everything depends on the degree of saturation employed. Hence it will be best to illustrate this by means of an actual example. In Fig. 7 six diagrams are shown representing the flux curves reproduced from actual oscillograms taken on one and the same machine. Along with the flux curves the M.M.F. curves are also given. The tooth ripples in the flux curves have been omitted, as they do not interest us just now. In this machine the rotor winding extended over three-quarters of the periphery, 12 slots being wound out of 16—that is, $\beta = 0{\cdot}75$. The excitation at

which the flux curves were taken is given below each diagram. Thus the curve *d* in Fig. 7 was taken with normal excitation at no load and is therefore designated 100 per cent. The flux curves are all taken to the same scale. To get a scale for the M.M.F. in these diagrams, the curve in Fig. 7 *a* was taken where practically no saturation was present, so that the flux at this point was strictly proportional to the M.M.F.

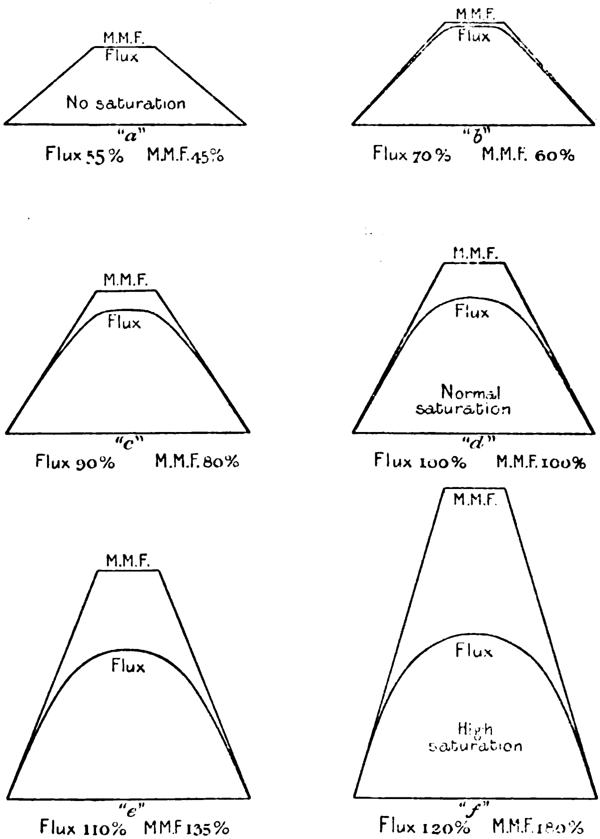


FIG. 7.—Flux and M.M.F. Curves of Non-salient Pole Machine with $\beta = 0{\cdot}75$.

Hence in this diagram the flux and M.M.F. diagrams can be taken as identical, the amplitude of the former being 55 per cent. and of the latter 45 per cent. with respect to the normal in each case. In this way of fixing the scales we can see how the flux curve increases with the M.M.F. Though the latter diagrams could equally well have been drawn to any other scale, their meaning would not have been so clear. Up to normal saturation, Fig. 7 *d*, the flux curve does not begin to flatten

seriously, though the corners become rounded off. Beyond the point of normal working, however, saturation plays a very important part, and it is seen from the small increase in flux with the large increase in excitation that these points lie high up on the magnetisation curve.

From this we see that saturation prevents the flux increasing in proportion with the excitation and causes the flux curve to bulge out or flatten. The higher the saturation the more the flux curve will be rounded off. We shall presently see, moreover, that the negative 3rd harmonic in the trapezium curve becomes a strong positive 3rd with high saturations.

In the neighbourhood of normal working, however, the departure from a sine wave is generally scarcely noticeable, the effect of normal saturation being merely to round off the trapezium curve into a wave closely resembling a sine curve.

The arguments applied above with respect to the value of β to machines without saturation also hold in general for machines with saturation, but we shall have more to say about this later on.

4. *Synthesis of Flux and Pressure Waves. Calculation of Open-circuit Characteristic.*—I now proceed to show how the flux and pressure waves for the non-salient pole type of alternator can be constructed. This is not a difficult matter, because the distribution of the M.M.F.—on which the shape of the flux curve so largely depends—is known, whilst the pressure wave follows directly from the flux curve. In the case of the ordinary salient pole machine, it will be recollected that the problem is by no means simple, for here both the distribution of the M.M.F. and the reluctance of the magnetic path over the pole-pitch are not easy to find. With the non-salient pole machine, however, there is no question whatever as to how the M.M.F. is distributed over the pole-pitch so long as it is known how the rotor is wound, which merely amounts to saying that we must know the particulars of the machine we have to calculate. Similarly the reluctance of the magnetic path is also easily determined provided the dimensions of the machine are known. Consequently it only becomes a matter of calculation to find the flux curve of a non-salient pole machine.

For our purpose, however, we will keep to the general case shown in Fig. 2 and construct the flux and pressure waves for a machine where the exciting winding is spread over a definite part of the periphery and has the same M.M.F. per slot over the wound portion. The rotor is slotted uniformly over the whole circumference and the air-gap is constant.

A. *The Magnetisation Curve.*—We start by calculating the magnetisation curve—that is, the relation between the flux density and the M.M.F. Suppose we assume a flux density B_g in the air-gap; then the flux-density B_x at any other part x of the magnetic circuit will be inversely proportional to the section at x. Taking the area of the gap as τL, where τ is the pole-pitch and L the total core length of the machine in centimetres, we have then—

$$B \times \tau L = B_x \times \text{section at } x,$$

or—

$$B_x = \frac{\tau L}{\text{section at } x} B_g.$$

In this way the density at any part of the magnetic circuit can be found, the respective section at x, of course, being taken over a whole pole to correspond with τ L.

Strictly speaking, however, this only holds for the air-gap and stator teeth. For the rotor teeth leakage has to be considered.

Hence we can write :—

Actual flux density at any point x in gap or stator teeth—

$$B_x = \frac{\tau L}{\text{section at } x} B_g.$$

Actual flux density at any point x in rotor teeth—

$$B_x = \frac{\tau L}{\text{section at } x} (B_g + B_l),$$

where B_l denotes the increase in density due to leakage. To calculate the flux density B_l due to leakage we must see how it acts. In Fig. 2 it is seen how the lines of force begin to fall away from the centre of the pole at the slots where the winding commences. Across the slots within the winding there can, of course, be no leakage, since no difference of magnetic potential exists. The two teeth just inside the coil nearest the pole-centre, therefore, carry less flux than the other teeth inside this coil. In this way the flux gradually falls away from the centre of the pole towards the teeth between consecutive poles. Here at last some flux finds a path in the gap and across the last two slots without touching the stator core, thus forming a leakage flux. An attempt to show this is made in Fig. 2, and a little consideration will show that the leakage flux on each side of the rotor is proportional to the total ampere conductors on that side, the reluctance of its path being formed by the slots in which these conductors are placed. Looked at in this way, the leakage flux on each side of the pole reduces itself to the M.M.F. of a slot divided by the reluctance of a slot or multiplied by the permeance of a slot. The calculation of the leakage flux is then quite simple and need not be detailed here. If magnetic wedges are used to close the slots, to reduce the tooth ripple, as has been assumed in the present case, the permeability of these must be taken into account. In passing it may be remarked that the above conception of leakage—viz., the rounding-off of the corners where the winding begins and the bulging-out of the flux curve—is actually borne out by oscillograms. In this way the corners of the M.M.F. trapezium become rounded off in the flux curve, making the latter more nearly sinusoidal. Thus leakage in non-salient pole rotors acts to some extent like saturation and would appear to be advantageous in this respect, but owing to the smallness of its magnitude it scarcely adds anything to the exciting current.

In this way the leakage flux has been determined and expressed as a flux density B_l. In passing, two points may be mentioned. First, to calculate the leakage flux we must, of course, know Σ A.T. per pole-pair. But Σ A.T. includes the ampere-turns for the rotor teeth, consequently we first rough out a value for Σ A.T., neglecting leakage, and from this estimate the leakage. We then calculate Σ A.T. again for the total flux density $B_g + B_l$ thus obtained, and see whether this agrees with the value of Σ A.T. for which B_l was estimated. Usually the agreement is quite good, so that no further calculation is necessary.

Secondly, in determining the ampere-turns for the rotor teeth it must be borne in mind that the saturations here may become very high. Consequently this part of the magnetic circuit must be suitably divided, and the actual densities obtained from the apparent densities at these parts.

In this way the ampere-turns for the gap and teeth are determined. There still remain the cores. Usually the M.M.F. required for these is not considerable, except in bipolar machines, where it may become important. Since, however, we do not wish further to lengthen the present calculation we shall not take the effect of the cores into consideration here.

Proceeding in this way, the magnetisation curve has been determined for a machine having the following particulars :—

Three-phase turbo-alternator—

600 k.w. at $\cos \phi = 0{\cdot}8$, 750 volts.
1,500 revs. per minute, 50 cycles, 4 poles.
Stator, 12 turns in series per phase.
Rotor, 13 slots per pole, 10 wound.

This magnetisation curve is given in Table VII. and shown plotted in Fig. 8. On this curve all the remaining calculations in this section will be based.

B. *The Flux Wave.*—It now becomes quite a simple matter to construct the flux curve. To do this it is best to proceed graphically. A convenient method is as follows : Draw the M.M.F. curve for the particular excitation at which the flux curve is required, and project from this curve a number of ordinates on to the magnetisation curve. The flux-densities corresponding to several M.M.F.'s are thus obtained, and can be projected as shown in Fig. 8 *b*, where they are drawn to a suitable base. Hence to find the flux wave it is only necessary to project the M.M.F. curve on to the abscissa axis of the magnetisation curve, and project the ordinates thus obtained on to the flux diagram. In this way the flux curves in Fig. 8 have been constructed for five different values of excitation, the method being clearly illustrated by Fig. 8 *b*, where the construction lines are shown. The five values of excitation chosen cover practically the whole range of the magnetisation curve, starting on the straight-line part of the curve for which the flux wave is a trapezium, and finishing at the highest point on the magnetisation curve, representing very strong saturation. The

flux curves for these two extremes are shown in Fig. 8 *a* and *e*, neither of which can be considered as practical. The three intermediate values, Figs. 8 *b*, *c*, and *d*, can be regarded as illustrating a machine working without saturation, with normal saturation, and with high saturation respectively, all being cases met with in practice. This range of curves, therefore, is of great interest and must be considered in detail.

We start by analysing the flux curves into their harmonics. Taking the fundamental as 100 per cent., the 3rd, 5th, and 7th harmonics are then as set forth in Table VIII.

The harmonics are shown dotted in the diagrams. It will be seen that the algebraic sum of the harmonics along the $\frac{\pi}{2}$ ordinate is practically equal to the amplitude of the flux curve in each case, thus

TABLE VII.

Magnetisation Curve of above Machine.

Assumed Value of B_g.	Σ A.T. per Pole-pair.
2,500	5,100
3,500	7,100
4,500	9,500
5,500	13,100
6,000	16,600
6,500	22,500

proving that all harmonics above the 7th are quite negligible, or even above the 5th, except in the first two cases. Moreover, neither the 5th nor the 7th are of any importance in practice, for these small harmonics practically vanish completely in the pressure waves.

The 3rd harmonic, however, is of importance, and the diagrams show well how the change in the shape of the flux curve is chiefly due to an influence which can be practically represented by this harmonic. It is very interesting to note how the triple harmonic commences by being negative in the trapezium ($\beta = 0{\cdot}77$ for 10 slots wound out of 13); it then becomes zero at Fig. 8 *c*, which is just below normal saturation; after then it is positive and represents the flattening and bulging out of the flux curve as the saturation is increased. Similar

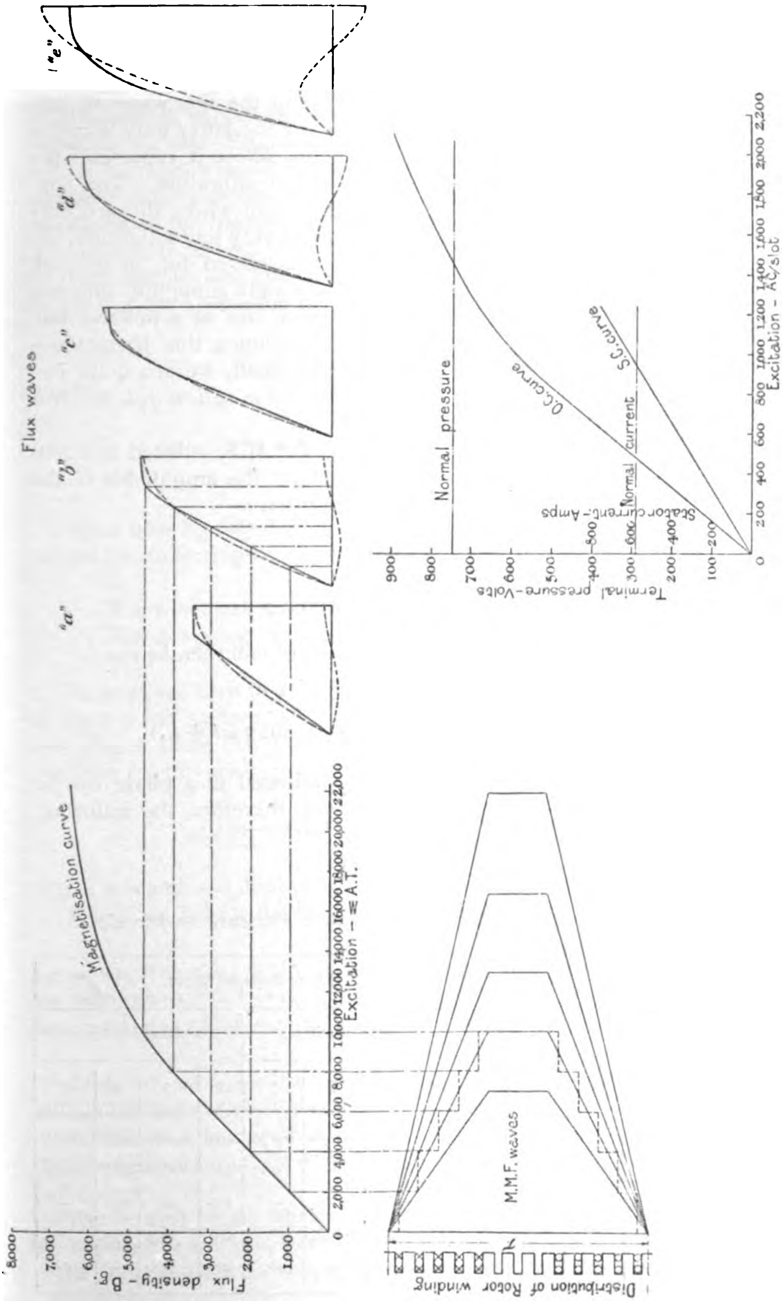

Flux waves
"a"
"b"
"c"
"d"
"e"
Magnetisation curve
Flux density - Bg.
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0 2,000 4,000 6,000 8,000 10,000 12,000 14,000 16,000 18,000 20,000 22,000
Excitation - w A.T.
M.M.F. waves
Distribution of Rotor winding
Normal pressure
O.C. curve
S.C. curve
Normal current
Stator current - Amps
100 200 300 400 500 600 700 800 900
Terminal pressure - Volts
0 200 400 600 800 1,000 1,200 1,400 1,600 1,800 2,000 2,200
Excitation - AC/slot

FIG. 8.

results were seen to obtain in the flux curves in Fig. 7, and are fairly general for this class of machine.

The result of this investigation, therefore, confirms the result arrived at in the earlier part of the paper, viz., that in the flux wave all harmonics above the 3rd can be neglected, and the latter only becomes of importance in highly saturated machines, where it represents the alteration in the shape of the flux curve due to saturation. This conclusion holds for all practical values of β. Cases where the 3rd harmonic is negative, *e.g.*, with $\beta = 0{\cdot}8$ or $0{\cdot}9$ and very low saturation, are not sufficiently important to be separately considered, for, in general, in normal machines the saturation is usually quite enough to suppress the negative 3rd harmonic, and even to give rise to a positive 3rd. Since, however, in normally saturated machines this harmonic—whether positive or negative—is usually so small, we are quite justified in saying that *the flux wave of a normal non-salient pole machine is practically a pure sine wave.*

C. *The Pressure Wave.*—Since the wave of E.M.F. induced in a conductor has the same shape as the flux wave, the amplitudes of the harmonics in the pressure wave can be written:—

$$E_1 \propto f_{\omega_1} B_1$$
$$E_3 \propto f_{\omega 3} B_3$$
$$E_5 \propto f_{\omega_5} B_5, \text{ etc.}$$

The equation for the pressure at any instant will then be:—

$$e_p = E_1 \sin \omega t + E_3 \sin 3\,\omega t + \ldots$$
$$= \text{const.}\ (f_{\omega_1} B_1 \sin \omega t + f\,\omega_3 B_3 \sin 3\,\omega t + \ldots)$$

whence the shape of the pressure wave induced in a phase can be obtained. In the present instance we get, therefore, the following table:—

TABLE VIII.

Harmonics in Waves of Flux and Phase Pressure in per Cent.

	Flux Wave.				Phase Pressure Wave.							
					3-phase Machine.				2-phase Machine.			
Harmonic:	1	3	5	7	1	3	5	7	1	3	5	7
Fig. 8 (*a*)	100	−5·00	−1·5	2·0	100	−3·3	−0·30	−0·30	100	−1·65	0·30	−0·30
(*b*)	100	−4·25	−1·3	1·7	100	−2·8	−0·25	−0·25	100	−1·40	0·25	−0·25
(*c*)	100	—	−2·0	—	100	—	−0·40	—	100	—	0·40	—
(*d*)	100	5·90	−1·8	—	100	3·9	−0·35	—	100	1·95	0·35	—
(*e*)	100	10·8	—	—	100	7·2	—	—	100	3·60	—	—

The effective phase pressure is—

$$E_p = \sqrt{\tfrac{1}{2}(E_1^2 + E_3^2 + \ldots)}.$$

Evaluating in terms of the above percentages, the difference between E_p and $E_1/\sqrt{2}$ is never $>$ 1 per cent. Consequently the higher harmonics have no influence on the effective pressure. The effective phase pressure, therefore, can be taken as proportional to the amplitude of the fundamental B_1 of the flux wave at any point on the magnetisation curve.

This fact at once enables us to determine the value of the E.M.F. factor k in the expression for the induced E.M.F., viz. :—

$$E_p = 4\, k\, c\, w\, \Phi\, 10^{-8},$$

where—

c = frequency
w = turns in series per phase
Φ = useful flux per pole.

Since now E_p only depends on the fundamental B_1 of the flux wave, we get the following constant value for k :—

For a 3-phase machine $k = f_B\, f_{\omega_1} = 1{\cdot}11 \times 0{\cdot}956 = 1{\cdot}06$.
For a 2-phase machine $k = f_B\, f_{\omega_1} = 1{\cdot}11 \times 0{\cdot}901 = 1{\cdot}0$.

If, now, we turn to a 3-phase machine with the phases interlinked to form a star system, we must add the respective harmonics in any two phases, these being displaced 120° from one another. Now, in the equation for the phase pressure e_p, the general terms are of the form—

$$\sin(n-2)\,\omega t + \sin n\,\omega t + \sin(n+2)\,\omega t,$$

where n is any odd multiple of 3.

Hence we get for the three phases at 120°—

$$e_{p\,\mathrm{I.}} = \sin(n-2)\,\omega t + \sin n\,\omega t + \sin(n+2)\,\omega t$$
$$e_{p\,\mathrm{II.}} = \sin(n-2)(\omega t - 120^\circ) + \sin n(\omega t - 120^\circ) + \sin(n+2)(\omega t - 120^\circ)$$
$$e_{p\,\mathrm{III.}} = \sin(n-2)(\omega t - 240^\circ) + \sin n(\omega t - 240^\circ) + \sin(n+2)(\omega t - 240^\circ).$$

Of the above terms it is seen that the n terms ($n = 3, 9, 15$, etc.) are always the same at any instant.

The $(n-2)$ terms (that is, $n - 2 = 1, 7, 13$, etc.) will always have the same direction of rotation as the fundamental, viz., $(\omega t - 120^\circ)$ and $(\omega t - 240^\circ)$.

The $(n+2)$ terms (that is, $n + 2 = 5, 11, 17$, etc.) always rotate in the opposite sense, viz., $(\omega t - 240^\circ)$ and $(\omega t - 120^\circ)$.

In summing up, $e_{p\,\mathrm{I.}} - e_{p\,\mathrm{II.}}$, $e_{p\,\mathrm{II.}} - e_{p\,\mathrm{III.}}$, and $e_{p\,\mathrm{III.}} - e_{p\,\mathrm{I.}}$, to obtain the

interlinked pressures, the n terms will then vanish, the $(n-2)$ terms will be multiplied by $\sqrt{3}$ (addition at 120°) and rotate in the same way as the fundamental, whilst the $(n+2)$ terms will be multiplied by $\sqrt{3}$ and rotate opposite to the fundamental.

Thus—

$$\longleftarrow\!\!-\!\!-\!\!-\!\!-\!\!-\!\!-\!\!\longrightarrow$$

$$\text{etc., } 29, 23, 17, 11, 5. \qquad 1, 7, 13, 19, 25, \text{ etc.}$$

Hence for the *interlinked or terminal pressure* we can write—

$$e_a = \text{const.}\,(\sqrt{3} f_{\omega 1} B_1 \sin \omega t - \sqrt{3} f_{\omega 5} B_5 \sin 5 \omega t + \sqrt{3} f_{\omega 7} B_7 \sin 7 \omega t - \ldots).$$

The shape of the interlinked pressure curve in the non-salient pole machine, therefore, will differ from the shape of the phase pressure curve for two reasons—

1. Absence of the 3rd harmonic.
2. Reversal of the 5th harmonic.

Again expressing the amplitude of the fundamental as 100 per cent., it is at once seen that the only higher harmonics now present are the 5th and 7th, which in the above example will never exceed 1 per cent. Thus the terminal pressure will be almost a pure sine wave at every point on the magnetisation curve.

The effective value E_λ of the terminal pressure will be—

$$E_\lambda = \sqrt{3} \text{ const.} \sqrt{\frac{1}{2}(E_1^2 + E_5^2 + \ldots)}.$$

Hence the ratio of E_λ to E_p is—

$$\frac{E_\lambda}{E_p} = \sqrt{3}\sqrt{\frac{E_1^2 + E_5^2 + \ldots}{E_1^2 + E_3^2 + E_5^2 + \ldots}} = \sqrt{3}\sqrt{\frac{1 + \left(\frac{E_5}{E_1}\right)^2 + \ldots}{1 + \left(\frac{E_3}{E_1}\right)^2 + \left(\frac{E_5}{E_1}\right)^2 + \ldots}}$$

Taking the worst case from the above table, the value under the root is never $< 0{\cdot}99$, so that the factor is reduced by < 1 per cent.

Thus we are quite justified in regarding the interlinked pressure also as proportional to the fundamental B_1 of the flux wave, and adopting the E.M.F. factor $k = \sqrt{3} f_B f_{\omega 1} = \sqrt{3} \times 1{\cdot}06 = 1{\cdot}84$, for a sine wave.

In conclusion, therefore, we can say that in a 3-phase non-salient pole machine, the terminal pressure is practically a pure sine wave under normal conditions. Similarly the phase pressure is usually so slightly distorted as to be scarcely distinguishable from a sine wave. The flux curve, however, may even under normal conditions depart from a pure sine law by the presence of a positive third harmonic, though this is usually of a very low order.

Hence the *production of a sinusoidal pressure curve under all no-load conditions is a characteristic of all non-salient pole turbo-alternators.*

Moreover, the origin of this sine-wave E.M.F. is not so much due to the disposition of the armature winding as to the sinusoidal flux curve. In earthing the neutral of 3-phase non-salient pole machines, therefore, no perceptible currents due to the 3rd harmonic will flow. Nor will there be any danger from connecting the winding mesh—an arrangement often convenient in high-speed machines for low pressures.

D. *The Open-circuit Characteristic.*—We have now seen how to find the shape of the flux and pressure waves from the magnetisation curve. From the flux curve the total flux per pole can be deduced, whence the open-circuit characteristic—that is, the relation between the flux or terminal pressure and the excitation—can be obtained.

Starting with the equation for the E.M.F., we have—

$$E = 4\,k\,c\,w\,\Phi\,10^{-8} \text{ volts,}$$

where—

c = frequency,
w = number of turns in series per phase,
Φ = useful flux per pole,
k = E.M.F. factor.

In the foregoing we have just seen that the value of k for a distributed stator winding is as follows :—

For a 3-phase winding—

$$E_p = f_B f_{\omega 1} = 1{\cdot}11 \times 0{\cdot}956 = 1{\cdot}06,$$
$$E_\lambda = \sqrt{3} f_B f_{\omega 1} = \sqrt{3} \times 1{\cdot}06 = 1{\cdot}84.$$

For a 2-phase winding—

$$E_p = f_B f_{\omega 1} = 1{\cdot}11 \times 0{\cdot}901 = 1{\cdot}0.$$

For any required E.M.F. the flux will then be—

$$\Phi = \frac{E \times 10^8}{4\,k\,c\,\omega}.$$

Now the flux Φ can be written—

$$\Phi = \tau\,L\,B_m,$$

where B_m = mean flux density in the gap. This gives a relation between Φ and B_m. We now proceed, therefore, to find Σ A.T. necessary for any given value of B_m.

Referring to the flux waves in Fig. 8, it is clear that for each of these waves there is a definite value of B_m, represented by the mean ordinate. Similarly, for each value of B_m, there is the corresponding maximum ordinate $B_{max.}$, represented by the amplitude of the respective flux wave. Lastly, the ampere-turns per pole-pair for $B_{max.}$ are

read off directly from the magnetisation curve, Fig. 8. Hence to find Σ A.T. for any value of Φ, it is only necessary to determine the connecting link between B_m and $B_{max.}$

This relation is easily found for such curves as we are dealing with. Among the several properties of these curves we have—

$$B_{mean} = B_m = \frac{2}{\pi}\left(B_1 + \frac{1}{3}B_3 + \frac{1}{5}B_5 + \frac{1}{7}B_7 + \ldots\right),$$
$$B_{max.} = B_1 - B_3 + B_5 - B_7 + - \ldots.$$

$B_{max.}$, of course, we can read off directly, whilst B_m is found from the above equation.

In this way the values in Table IX. have been found, whence we can plot $B_{max.}$ as a function of B_m.

TABLE IX.

Maximum and Mean Ordinates of Flux Waves.

Fig. 8.	$B_{max.}$	B_m.
a	3,450	2,120
b	4,750	2,950
c	5,550	3,600
d	6,100	4,150
e	6,550	4,850

Hence, to find the requisite ampere-turns for a given flux, we proceed thus—

1. Find $B_m = \frac{\Phi}{\tau L}$.
2. Find $B_{max.}$ corresponding to B_m.
3. Find Σ A.T. corresponding to $B_{max.}$

Turning now to the machine in question, which is wound 3-phase, star-connected, we have :—

$$\Phi = \frac{E_\lambda 10^8}{4kcw} = \frac{E_\lambda\ 10^2}{4 \times 1{\cdot}84 \times 50 \times 12} 10^6$$
$$= 0{\cdot}0227\ E_\lambda\ 10^6$$

$$B_m = \frac{\Phi}{\tau L} = \frac{\Phi}{4500}.$$

The open-circuit characteristic is shown calculated in Table X., and can now be drawn with either the terminal pressure or flux as ordinates and the ampere-turns per pole-pair or ampere conductors per slot as abscissæ. The latter form is very handy for machines of this type, and is found very simply for a rotor with the same number of conductors in each slot. Thus—

$$\text{A.C./slot} = \frac{\Sigma \text{ A.T. per pole-pair}}{\frac{1}{2} \times \text{number of wound slots per pole-pair}}.$$
$$= \frac{\Sigma \text{ A.T. per pole-pair}}{\text{number of wound slots per pole}}.$$

If all the conductors are in series we also have—

$$\text{Exciting current} = \frac{\text{A.C./slot}}{\text{conductors per slot}} \text{ amperes.}$$

In Fig. 8 the open-circuit curve has been plotted with E_λ as a function of A.C./slot. It should be also noticed that since $B_{max.}$ is known for any desired flux or E.M.F., it at once becomes possible to

TABLE X.

Calculation of Open-circuit Characteristic.

Terminal Pressure, $\Sigma\lambda$.	Flux Φ $= 0{\cdot}0227\, E_\lambda \cdot 10^6$.	B_m $= \Phi/4{,}500$.	$B_{max.}$ $= f(B_m)$.	Σ A.T. (Fig. 8.)	A.C./slot $= \frac{\Sigma \text{ A.T.}}{10}$
300	$6{\cdot}8 \times 10^6$	1,510	2,480	5,000	500
500	11·3	2,520	4,040	8,300	830
700	15·9	3,540	5,440	12,700	1,270
800	18·1	4,020	6,000	16,500	1,650
900	20·4	4,540	6,380	21,000	2,100

find the actual density in any part of the magnetic circuit under any given condition.

Of course the above method is not given as a typical way of finding the open-circuit curve, which would be far too roundabout and tedious in practice.

A somewhat simpler method, also based on first principles, is to assume the excitation—either Σ A.T. or A.C./slot—and determine Φ or E_λ, instead of *vice versâ*. To illustrate this we will assume we have 1,500

A.C./slot = 1,500 ampere-turns per slot-pair = 10 × 1,500 ampere-turns per pole-pair. To find B_m we now proceed thus. On the four middle teeth there are 15,000 ampere-turns acting; on the two teeth inside the first coil there are $\frac{4}{5}$ × 15,000 = 12,000 ampere-turns acting; on the next two $\frac{3}{5}$ × 15,000 = 9,000 act, and so on, until last of all there is one tooth on which no M.M.F. acts at all. This is shown in the following Table :—

TABLE XI.

Mean Flux Density B_m *for* 1,500 A.C./*slot.*

Number of Teeth Affected, M.	Σ A.T.	B_g	M × B_g.
4	15,000	5,800	23,200
2	12,000	5,250	10,500
2	9,000	4,300	8,600
2	6,000	3,000	6,000
2	3,000	1,500	3,000
1	0	0	0

$\Sigma(M \times B_g) = 51300.$

Hence—

$$B_m = \frac{\Sigma(M \times B_g)}{\text{teeth per pole}} = \frac{51300}{13} = 3950.$$

And—

$$\Phi = \tau L B_m = 4500 \times 3950 = 17{\cdot}7 \times 10^6,$$

whence—

$$E_\gamma = 44\,\Phi \times 10^{-6} = 44 \times 17{\cdot}7 = 780 \text{ volts},$$

which agrees with the value obtained by the former method, as seen from the open-circuit curve in Fig. 8.

Similarly for any other value of the excitation, the corresponding flux or pressure can be found.

In this way the open-circuit characteristic can be accurately obtained from the magnetisation curve of the machine, without determining the mean density B_m from the flux waves.

There are, of course, other methods of finding the open-circuit curve, some of which do not necessitate the determination of the magnetisation curve. The method above described—though somewhat tedious—is nevertheless simple and accurate, and is sufficient for our present purpose.

5. *Effect of Load.*—It has already been shown that the pressure wave of a non-salient pole machine is almost a pure sine wave on no load. Such a wave, therefore, will only produce sinusoidal currents if the load consist of apparatus whose resistance, inductance, or capacity

is constant with respect to the fundamental. In practice, however, it frequently happens that this is not the case, in consequence of which the current wave suffers distortion. The pressure wave may also become distorted, due to other machines in the system which generate E.M.F.'s differing from a sine wave.

It is not my intention, however, to deal with this general problem here, but only to treat the case where the current curve has the same shape as the pressure curve—viz., a sine wave, an assumption which —provided no abnormal conditions of load occur—is by no means unjustifiable in the non-salient pole machine, where we have this wave-shape to start with on no load. We now proceed to show what effect

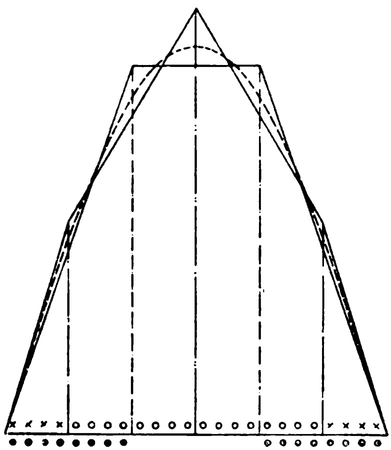


FIG. 9.—Distribution of Stator M.M.F.

Mean Ordinate of Equivalent Sine Curve = $0{\cdot}581\, q\, z\, I \sqrt{2}$.

such a load will have on the flux and pressure curves in the non-salient pole machine.

When an alternator is working on load, the exciting current has to be increased in order to maintain constant pressure at the terminals. This increase of excitation is due mainly to three causes :—

1. Armature reaction.
2. Leakage of stator winding.
3. Leakage of rotor winding.

Now, the last cause need not delay us further here, because in a cylindrical rotor the leakage from pole to pole—as seen in Section 4—is usually very small, and the flux curve is little affected in shape thereby. Nor is the second cause—viz., leakage of stator winding of

sufficient importance to need special consideration, as this is generally comparatively low in turbo-alternators, and produces but little effect on the excitation.

Armature Reaction.—Of primary importance is armature reaction; and the effect of this must now be considered. Since, now, the load-current varies after a sine wave we can at once find the M.M.F. curve of the stator winding. Assuming this to be a 3-phase winding, with each phase covering 60°—*i.e.*, the number of slots per pole and phase are sufficiently large to form a distributed winding, which is usually the case with turbo-alternators—we then get the M.M.F. curve varying between the trapezium and the pointed curve in Fig. 9.

The equivalent sine wave of M.M.F. is shown dotted, and can be taken to represent the mean effect without introducing any appreciable error. Thus, the two M.M.F. block curves will be replaced by their equivalent sine curve, the values of which per pole are given in Table XII.

TABLE XII.

Value.	Sine.	Trapezium.	Pointed.	
Maximum...	0·913	0·866	1·000	$\times q z I \sqrt{2}$
Mean ...	0·581	0·578	0·583	$\times q z I \sqrt{2}$
Effective ...	0·646	0·646	0·646	$\times q z I \sqrt{2}$

where I is the effective armature current.

In this way it is seen that the armature reaction, or the M.M.F. due to the armature current, is practically sinusoidally distributed over the

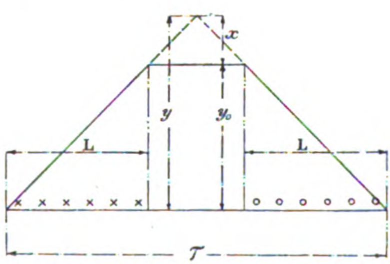


FIG 10.—Distribution of Rotor M.M.F.

Mean Ordinate of Trapezium $= \frac{1}{2} y \left(1 - \frac{x^2}{y^2}\right)$.

pole-pitch, when the load current varies after a sine law. Thus the M.M.F. curve due to the load current is a sine wave, whilst that due to

the exciting current is a trapezium, though differing but little from a sine wave. We must now see what the resultant of these two M.M.F. curves will be, for on this resultant depends the shape of the flux curves.

Before proceeding to find the resultant we must first reduce the stator ampere-turns to the rotor, since the former have to be counter-balanced by the latter. To do this it is only necessary to find the mean ordinate of rotor ampere-turns equivalent to the mean ordinate of stator ampere-turns. Now, the mean ordinate of the stator M.M.F. is (see above table) $0{\cdot}58\, q\, z\, \mathrm{I}\, \sqrt{2}$ per pole, or $1{\cdot}16\, q\, z\, \mathrm{I}\, \sqrt{2}$ per pole-pair.

For the mean ordinate of the rotor M.M.F. consider Fig. 10. Let the trapezium denote the curve of M.M.F. per pole due to the exciting winding. Then—

Area of the complete triangle—

$$=\tfrac{1}{2} r y$$

Area of the part cut off—

$$=\tfrac{1}{2} r y \frac{x^2}{y^2}.$$

Hence area of M.M.F. curve (trapezium)—

$$=\tfrac{1}{2} r y\left(1-\frac{x^2}{y^2}\right),$$

and its mean ordinate—

$$=\tfrac{1}{2} y\left(1-\frac{x^2}{y^2}\right).$$

Hence mean M.M.F. per pole-pair—

$$=y\left(1-\frac{x^2}{y^2}\right).$$

Let now the ampere conductors per slot over the wound part be denoted, as before, by A.C./slot.

Further, let—

$$\mathrm{N}=\text{total number of slots per pole-pitch},$$

and—

$$\mathrm{N}_0=\text{number of slots wound per pole-pitch}.$$

Then the ordinate—

$$y=\frac{\mathrm{N}}{2}\times \text{A.C./slot},$$

and the ratio—

$$\frac{x}{y}=\frac{\mathrm{N}-\mathrm{N}_0}{\mathrm{N}}=1-\beta.$$

Equating now the mean ordinates of stator and rotor M.M.F., we have for a pole-pair—

$$y\left(1 - \frac{x^2}{y^2}\right) = 1 \cdot 16\, q\, z\, \mathrm{I}\ \sqrt{2},$$

or substituting for y and $\frac{x}{y}$:

$$\frac{\mathrm{N}}{2}\ \text{A.C./slot}\ [1 - (1 - \beta)^2] = 1 \cdot 16\, q\, z\, \mathrm{I}\ \sqrt{2},$$

or—

$$\frac{\mathrm{N}}{2}\ \text{A.C./slot}\ (2\beta - \beta^2) = 1 \cdot 16\, q\, z\, \mathrm{I}\ \sqrt{2},$$

whence A.C./slot—

$$= \frac{2 \times 1 \cdot 16\, q\, z\, \mathrm{I}\ \sqrt{2}}{\mathrm{N}\ (2\beta - \beta^2)} = \frac{2 \cdot 32\ \sqrt{2}}{2\beta - \beta^2} \cdot \frac{q\, z\, \mathrm{I}}{\mathrm{N}} = k_a \frac{q\, z\, \mathrm{I}}{\mathrm{N}},$$

where k_a is an ampere-turns factor.

This, then, is the armature reaction in terms of A.C./slot on the rotor.

The value of k_a can be taken from the following table :—

TABLE XIII.

Value of β.	Factor $k_a = \frac{2 \cdot 32\ \sqrt{2}}{2\beta - \beta^2}$.
0·9	3·3
0·8	3·4
0·7	3·6
0·6	3·9

This is now in a convenient form for reducing the stator M.M.F. to the rotor, and if we neglect the small effect of stator leakage we can write—

$$\frac{\mathrm{I}_k}{\mathrm{I}} = \frac{\text{A.C./slot on no load}}{k_a \frac{q\, z\, \mathrm{I}}{\mathrm{N}}},$$

where I_k is the short-circuit current due to no-load excitation.

Having found the armature reaction in terms of the rotor ampere-turns, we can at once draw the short-circuit characteristic and the

M.M.F. diagram, as for a salient pole machine. In this way, the short-circuit curve in Fig. 8 has been drawn. For the M.M.F. diagram, we shall not go into refinements by taking the pressure drop due to the stator resistance and reactance into account, which are seldom considerable in turbo-alternators. It will be quite sufficient for our present purpose if we consider the armature reaction due to the stator ampere-turns alone and take the phase displacement as entirely due to the load. In this way we get the simple M.M.F. diagram shown in Fig. 11.

The diagram is based on $\frac{I_t}{I} = \frac{1200}{800}$, where A.C./slot = 1,200 is the no-load excitation and A.C./slot = 800 is the equivalent armature reaction. Thus the excitation on full load will be 1,450 A.C./slot on unity power factor and 1,800 A.C./slot at $\cos\phi = 0{\cdot}8$.

This brings us to one of the fundamental differences between the non-salient pole machine and the salient pole machine.

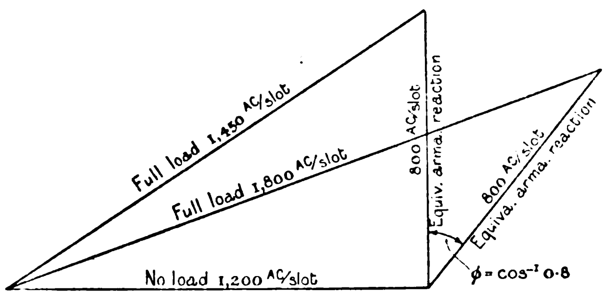


FIG. 11.—M.M.F. Diagram of Non-salient Pole Machine.

In an alternator the effect of armature reaction depends on the phase displacement of the armature current with respect to the induced E.M.F. or flux. With an inductive load, $\cos\phi = 0$, the armature ampere-turns exert a purely demagnetising effect; with a non-inductive load, $\cos\phi = 1{\cdot}0$, a purely distorting action. In other words, at zero power factor the armature and field ampere-turns directly oppose one another, whilst at unity power factor they are displaced 90° from one another. At intermediate positions the effect is partly demagnetising and partly distorting. The effect of this on the shape of the flux curve in a salient pole machine is well known and the skewed distorted flux and pressure curves are quite familiar. In a non-salient pole machine, however, none of this skewing occurs. The reason for this is two-fold.

1. Both stator and rotor M.M.F. curves are practically sine waves.
2. The reluctance of the magnetic path is constant for any position of the flux.

Hence when a load comes on, the flux curve simply assumes a new position in space according to the phase of the load current. Since,

however, the sum of two sine curves of the same frequency at any angle is also a sine curve the shape of the flux curve is not affected. Provided, therefore, that the excitation is increased to overcome armature reaction, that is, to maintain constant pressure, the flux curve on load will to all intents and purposes be the same as on no load, for, no matter what position it assumes in space, the reluctance of the magnetic path is constant. Under these conditions it is not difficult to see that the shape of the pressure wave is unaffected by the nature of the load.

Thus the M.M.F. diagram is also the vector diagram of the mean M.M.F.'s forming the flux curve ; the armature and field components, along with their resultant, all being sinusoidal.

Electrically speaking, therefore, the non-salient pole alternator is an ideal machine, possessing the inherent characteristics of a sinusoidal flux and pressure wave under all conditions of load and no load.

It must be borne in mind, however, that the ideal condition of a constant reluctance of the magnetic path only holds for the uniformly slotted rotor, with constant air-gap (Fig. 2). For any other arrangement the above arguments must be modified accordingly. Indeed, as a general statement it might also be added that from all points of view—both electrical and mechanical—the uniformly slotted rotor with constant air-gap appears to be the ideal arrangement for the non-salient pole machine.

6. *Standardisation.*—In conclusion, it only remains to show how the non-salient pole turbo-alternator lends itself readily to standardisation. If we take, for example, the frequency of 50 cycles per second as standard we at once have the following possible turbine speeds :—

Number of Poles.	Speed.	Output.
	Revs. per Minute.	
2	3,000	Up to 2,000 k.w.
4	1,500	Up to 5,000 ,,
6	1,000	Above 5,000 ,,

This already is an enormous simplification.

Going further it is at once apparent that as few diameters as possible will be chosen for each speed, the greatest, of course, being limited by the maximum permissible peripheral speed, and the others to obtain suitable lengths for the required outputs. Pushing this argument further, it at once suggests itself to standardise each diameter as a type, and to vary the output obtainable from this type by altering the length of the machine. Thus the cross-section of any one type will be the same for all lengths, so that the air-gap, teeth, and cores will all be identical. From this it at once follows that the open-circuit

curve will be one and the same for all machines of any one type. Hence if we plot a curve with, say, the flux per centimetre (*i.e.*, Φ/L) as a function of the ampere conductors per slot (A.C./slot) this curve will be a characteristic of the type in question.

If, therefore, we choose minimum and maximum core lengths for a given diameter and retain the same section throughout, the outputs can be adjusted on the "telescopic" principle, according to the guarantees required. This, then, at once reduces the standardisation of non-salient pole-turbos to a matter of great simplicity. When once the above characteristic curve is known (measured or calculated), and also the heating limits, all else is immaterial. This means, of course, that

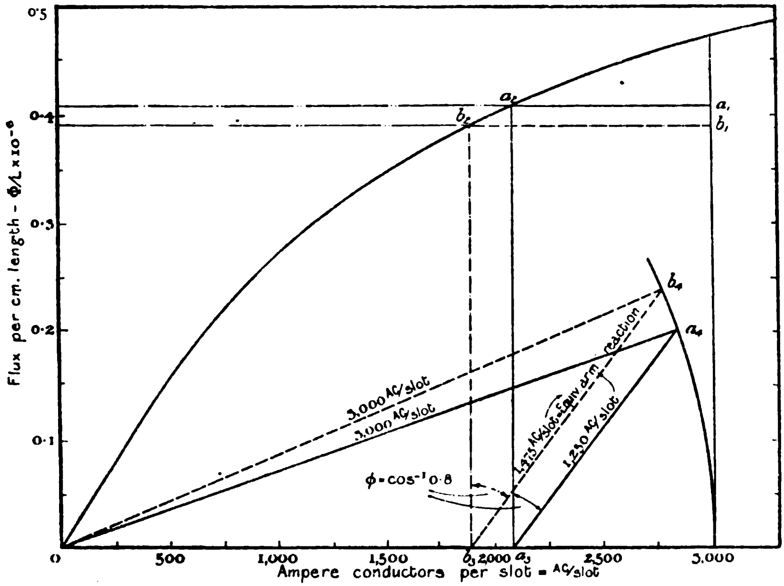


FIG. 12.—Characteristic Curve of given Type of Non-salient Pole Machine.

the output of the rotor is known, or in other words, the permissible A.C./slot for a given length—a matter only determined by experience.

To illustrate this method of standardisation the co-ordinates of an open-circuit curve have been thus reduced to flux per centimetre and A.C./slot and plotted in Fig. 12. We shall now see how the length L of the machine can be determined for any required output (within the limits of the type), and also how the output is affected by regulation.

For the sake of simplicity, let us assume the maximum permissible A.C./slot in this machine is constant for all lengths and equals 3,000. Further, in increasing the length the section axially must not alter; that is, the spacing of the ducts, and so on, must remain the same.

Actually the permissible A.C./slot will vary with the length of the machine, because the rotor heating does not increase so fast as the length on account of the large constant term introduced by the heating of the overhang of the exciting winding. On the other hand, the ventilation of a long machine is not so good, which acts as an offset to the above. For our purpose, however, the actual permissible values of rotor heating need not concern us, and we shall take the maximum A.C./slot for a definite temperature rise as constant for all lengths.

Starting, then, with the characteristic curve of this type, we can at once standardise the outputs under various conditions of regulation, power factor, and the like. To illustrate this we will consider a few problems.

Problem 1.—Given a 3-phase machine to have an output of 600 k.w. at $\cos\phi = 0{\cdot}8$, 1,000 volts. Find the total core-length L, when the required regulation is—

(*a*) 25 per cent. (*b*) 20 per cent. (*c*) 15 per cent.

Problem 2.—Given a total core-length of 60 cm., find how the output varies with the regulation on a power factor of 80 per cent.

Problem 3.—Taking 21 per cent. as the regulation at $\cos\phi = 0{\cdot}8$, find the range of outputs between the limits of core-length $L = 40$ to 80 cm.

Problem 1.—

$$600 \text{ k.w. at } \cos\phi = 0{\cdot}8 = 750 \text{ kilovolt-amperes.}$$

Current—

$$I = \frac{\text{k.v.a.}}{\sqrt{3}\, E_\lambda} 1000 = 435 \text{ amperes.}$$

Equivalent armature reaction—

$$\text{A.C./slot} = k_a \frac{I q z}{N};$$

whence—

$$q z = \frac{N}{k_a I} \text{A.C./slot} = \frac{16}{3{\cdot}3 \times 435} \times \text{A.C./slot} = 0{\cdot}011 \text{ A.C./slot.}$$

Flux—

$$\Phi = \frac{E_\lambda \,.\, 10^8}{4 k c p q z} = \frac{272}{q z} 10^6.$$

Length—

$$L = \Phi \div \Phi/L.$$

Turning now to Fig. 12, we draw an ordinate at 3,000 A.C./slot, and so find the point a_1, corresponding to 15 per cent. voltage rise. From this we at once get the points a_2, a_3, and a_4, whence the equivalent armature reaction is at once found—viz., A.C./slot = 1,250. From this $q z$, Φ, and L are obtained. Proceeding similarly for the other points, we get the following table:—

Table XIV.

Effect of Regulation on Length of Machine for a given Output.

Regulation.	A.C. slot.	$q z$.	$\Phi \times 10^{-6}$.	$\Phi/L \times 10^{-6}$.	L.
Per Cent. 25	1,600	18	15·1	0·376	40
20	1,450	16	17·0	0·392	44
15	1,250	14	19·4	0·408	48

It must be here remarked that the above figures are not strictly accurate for obvious reasons. It is, however, quite unnecessary to go into refinements, such as stator leakage, which would make the regulation somewhat worse than that found in this way. Also the value of $q z$ must be rounded off to make a possible value—in low-pressure machines this may upset the design considerably.

The above figures show that the length of the machine must be considerably increased if close regulation is required.

Problem 2.—Take a point b_1 on the ordinate through A.C./slot 3,000 and construct the M.M.F. diagram O, b_3 b_4. The regulation, then, at this point b_1 is 21 per cent., and the equivalent armature reaction = 1,475 A.C./slot. To find the output we have—

Pressure—

$$\begin{aligned} E_\lambda &= 4 k c p q z \Phi 10^{-8} \\ &= 4 \times 1{\cdot}84 \times 50 \times q z \Phi 10^{-8} \\ &= 3{\cdot}68\, q z \Phi 10^{-6}. \end{aligned}$$

Flux—

$$\Phi = \Phi/L \times L = 60\,\Phi/L.$$

Current—

$$\begin{aligned} I &= \frac{N}{k_a q z} \text{A.C./slot} = \frac{16}{3{\cdot}3} \frac{\text{A.C./slot}}{q z} \\ &= 4{\cdot}85 \frac{\text{A.C./slot}}{q z}. \end{aligned}$$

Output—

$$\begin{aligned} \text{k.v.a.} &= \frac{\sqrt{3}\, E_\lambda I}{1000} \\ &= \frac{\sqrt{3}}{1000} \times 3{\cdot}68\, q z \Phi 10^{-6} \times 4{\cdot}85 \frac{\text{A.C./slot}}{q z} \\ &= 0{\cdot}031 \,.\, \text{A.C./slot}\ \Phi\ 10^{-6}. \end{aligned}$$

Taking a number of such points on the characteristic curve we find the figures given in Table XV.

The first and last cases in this table are perhaps well up to practical limits, whilst the remaining cases are more normal. It is seen how the output of the machine can be raised by letting the regulation go. In the above examples, of course, the pressure and current can be adjusted as required, provided the flux per centimetre and A.C./slot are kept the same as in the table.

TABLE XV.

Effect of Regulation on Output of Given Machine.

Regulation.	$\Phi/L \times 10^{-6}$.	$\Phi \times 10^{-6}$.	A.C./slot.	Kilovolt-amperes.
Per Cent.				
9·5	0·43	25·8	925	740
15·0	0·41	24·6	1,225	935
21·0	0·39	23·4	1,475	1,070
28·0	0·37	22·2	1,650	1,135
35·0	0·35	21·0	1,850	1,200

Problem 3.—For the 21 per cent. regulation the point at which we work on the open-circuit curve is b_2, where $\Phi/L = 0·39 \times 10^6$.

Then we have, as in Problem 2—

Flux—

$$\Phi = L \times \Phi/L = 0·39\, L \times 10^6.$$

Output—

$$\begin{aligned} \text{k.v.a.} &= 0·031 \times \text{A.C./slot}\ \Phi\ 10^{-6} \\ &= 0·031 \times 1475\ \Phi\ 10^{-6} \\ &= 45·7 \times \Phi\ 10^{-6} \\ &= 45·7 \times 0·39\, L \\ &= 17·8\, L. \end{aligned}$$

Thus the output is directly proportional to the length, and the limits for 40 and 80 cm. are 700 and 1,400 k.v.a. respectively.

There is no need to carry the above illustrations further, as they are quite sufficient to show how readily the non-salient pole machine adapts itself to standardisation. In practice, of course, there are a number of details which must be taken into account and may modify the above results considerably, but these also are matters for practical experience.

In concluding the paper, I must again draw attention to the fact that the above arguments are all based on the non-salient pole machine with the rotor slotted uniformly over the whole periphery, each of the wound slots producing the same M.M.F. The air-gap also is constant

throughout. Hence the above ideal conditions of working which have been deduced for this machine will have to be modified if this arrangement is departed from.

In addition to the points dealt with in this paper there are also certain others connected with this type of machine which have not been discussed. For example, the influence of the teeth with respect to the ripple it superposes on the pressure wave is an important matter. But this along with other items must be reserved for a future discussion.

As a last word, the author would like to express his thanks to Mr. R. G. Jakeman for the way in which he has actively assisted in the preparation of this paper, to Mr. R. Orsettich for his kindly criticism, and to Mr. M. J. Railing for the facilities he has placed at the author's disposal.

Discussion before the Birmingham Local Section.

Mr. A. M. Taylor: The point in which I am most interested is that of regulation. In Table XV. the author gives us 15 per cent. regulation with 935 kilovolt-amperes, and 28 per cent. with 1,135 kilovolt-amperes. Presumably the object of the author is to bring home to engineers how much cheaper it is for a given kilovolt-ampere output to put in a machine having a poor regulation. The reduction of the short-circuit current is closely linked up with this question of regulation, and, in fact, is the pretext for introducing the poor regulation. Taking the second of the two outputs quoted, the drop from no load to full load would apparently be, in the case of a 5,000-volt machine, from 5,000 to 3,900 volts. If, however, instead of the full-load current we had a short-circuit current of, say, ten times this amount, a terminal voltage of zero would be reached (given sufficient time) before the short-circuit current had attained to the dimensions of $4\frac{1}{2}$ times the full-load current. No doubt such a drop in voltage as that just indicated would not actually occur even with ten times the full-load current, owing to the fact that the eddy currents induced in the rotor would prevent the wiping out of the rotor flux, and it would be interesting if the author would tell us if he has made any estimation of the actual reduction in voltage that might be expected in, say, the $\frac{1}{100}$ part of a second. Considering, however, that there will be twice the number of demagnetising ampere-turns in the stator that are necessary to reduce the rotor field to zero, it seems to me highly probable that the reduction in the rotor flux would be of the order of from 50 to 70 per cent., and I should like to know from the author whether this might not be expected. This raises the point as to whether such a drop, supposing the short circuit to occur between the generating station and one of the sub-stations, would not be sufficient to throw the rotaries at the sub-station out of step, as these would be giving, for the instant, their full E.M.F. of 5,000 volts, and would be converted into generators discharging into a circuit of extremely small resistance in Mr. Taylor.

Mr. Taylor. which the counter E.M.F. (namely, that at the generating station) would be only some 2,000 volts, leaving an effective voltage of some 3,000 volts to drive current through a circuit of exceedingly low resistance. No doubt the conditions would be mitigated by the fact of the rotary converters themselves dropping their E.M.F. quite materially, but, even so, the short-circuit current from these rotaries would suffice to throw them out of step. It seems desirable that, before engineers agree with a light heart to sacrifice all regulation in the generators at the main station, they ought to be assured that in doing so they are not incurring the risk of throwing the synchronous machinery at the sub-station out of step.

Dr. Kahn. Dr. M. KAHN: The paper has special merits, as it is the first treatise in which the electrical qualities of the non-salient pole rotor have been extensively dealt with in a precise way and a mathematical analysis of these qualities given. It is a most valuable contribution to the controversy between the non-salient pole and the salient pole types of rotor, and it shows the excellent electrical qualities of the non-salient pole type, as this type gives a sine-wave voltage curve independent of the load, if the exciting winding is properly distributed. The paper is, therefore, a useful addition to previous papers in which the perfect mechanical qualities and the good heat dissipation of the non-salient pole type of rotor have been explained. I should not like to let this occasion pass without mentioning the name of Charles Brown, to whose inventive spirit we are indebted for the type of rotor in question. The precise mathematical treatment of this type of rotor is to-day of greater importance than ever. The speed of turbo-alternators has been increased considerably in recent years, and nowadays machines of 2,000 and 3,000 kilovolt-amperes have to be designed at 3,000 revs. per minute and 5,000- and 6,000-k.w. machines at 1,500 revs. per minute. This can only be done if the material in the rotor is used to the best advantage, and a very serious consideration in the design of these rotors is the selection of the correct value, β, for the ratio of the wound portion to the unwound portion of the rotor circumference. It is evident from the paper that it has absolutely no value if the whole circumference is wound, since if 90 per cent. of the circumference is wound ($\beta = 0{\cdot}9$) only 91 per cent. of the ampere-turns are required, so that the other 10 per cent. of winding would be wasted. On the other hand, it is desirable to distribute the winding over as much as possible of the circumference available for winding, to keep the heating down, and it is therefore not desirable to decrease the value of β too much, especially on 2-pole machines. In the case of 2-pole machines a value of β of 0·7 to 0·8 would probably be found to give the most economic designs. In 4-pole machines a smaller value may often be found sufficient to accommodate the rotor winding. It is interesting to see from the tables given in the paper that these values also give M.M.F. curves nearest to sine waves. The question of regulation has already been mentioned in the discussion. The paper shows what influence the regulation has on the size of the alternator. I think, however, that

the figures given do not show this influence sufficiently. Table XV. indicates that if the regulation is increased from 15 per cent. to 28 per cent. the output is increased from 935 to 1,135 kilovolt-amperes. I think that the difference in output would be considerably greater. Dr. Kahn.

Mr. N. PENSABENE-PEREZ : The method of investigation employed by the author is not to my liking in so far as, while being lengthy and tedious, it is also inaccurate, being built up on very rough and unstable ground, made up of assumptions and simplifications which are necessary for a general analytical treatment of an engineering character. The author, in his desire to decompose the field curve into its harmonics, has been obliged to assume a very simple trapezium curve, and this he has done by neglecting the M.M.F. steps, the saturation of the iron, and the reluctance of the slots. To my mind, the graphical method in which it is possible to trace the shape of the flux curve by taking into consideration the above-mentioned elements, is much more accurate and infinitely simpler. The effect of slot reluctance in the E.M.F. wave-form is a very important one in turbo-alternators, where the slots are generally larger than the teeth. I have had occasion to compare two machines of the axial-slot type built by the Electric Construction Company, one fitted with phosphor-bronze wedges to keep the winding in the slots, and the other fitted with steel wedges. While a larger third harmonic was present in the first-mentioned machine, an almost sinusoidal curve was obtained in the other type. Deep steel wedges are most desirable in turbo-alternators, because by doing away with sudden changes of flux density in the flux curve no sudden drop of E.M.F. takes place between coils in the adjacent armature slots. Also this practice tends to increase the rotor leakage and permits of higher saturation being reached. The armature leakage is also increased, but this is a very welcome element in turbo-alternators, in which short-circuit currents may reach enormous magnitude. I agree with the author that in the non-salient pole type the E.M.F. wave-form is not deformed by the load, but I doubt if this constitutes a serious advantage. In my opinion the real advantage of non-salient pole type is purely mechanical, and electrical in so far as it will be possible with such construction to push much further the losses in the field winding, as the cooling of the distributed winding is much more effective, taking place principally by conduction to the iron mass. Mr Pensabene-Perez.

Mr. H. W. TAYLOR : I have had occasion to apply analytical methods similar to those used in the paper to a special form of the non-salient pole machine, and have had very satisfactory results. I feel, however, that although the method may be sound, many of the conclusions stated by the author as of general application to the non-salient pole type of machine should only be applied to the particular type dealt with by the author, and are not justified when used with reference to some of the other forms of construction which are being used by various firms. I do not agree with the statements made on page 591, viz., that the leakage of the stator windings is comparatively low. I Mr. Taylor.

Mr. Taylor. am aware that in many of the earlier machines this was the case, but I think that in modern machines it has become a matter of importance—I would even say of necessity—that the reactance assumed a reasonable figure. Speaking of reactance leads to the question of regulation, and I am surprised to see on page 597 a machine suggested with a regulation of 15 per cent., or even 20 per cent. at 80 per cent. power factor. Makers of machines had for some time been trying to get central station engineers to adopt a machine with coarse regulation, and to have the voltage maintained constant within a small percentage by means of an automatic regulator. The object of this from a designer's point of view is that, owing to the high speed and to the construction which has been adopted to withstand it, a short circuit on the machine will be very severe, and very large mechanical and electrical forces are brought to bear upon the various parts of the machine, including stator and rotor windings, stator housing, the shaft, the coupling, and even the turbine itself. In order to cope better with these forces it is desirable to limit the value of the short-circuit current, and this may be arranged by building the machine with a coarse regulation. This machine would probably be cheaper than the close regulating machine by an amount more than equal to the extra price of the regulator. Engineers objected that the regulator might fail, but, while not admitting such a possibility with the perfected regulator of to-day, it may be pointed out that a rise of 15 per cent. will be as disastrous to lamps and other apparatus on the circuit as the coarsest regulation which designers might offer. It must be remembered, further, that on large machines the variations in power are small in proportion to the ratings of the machines, so that even without a regulator a hand control of the voltage is quite easy, even with a coarse regulation between full and no load. Speaking from a practical point of view, I am afraid that the scheme of standardisation briefly outlined by the author would not be found so simple as might at first sight appear. It need only be pointed out that a manufacturer has to consider the question of standardisation much more broadly and with reference to all his various customers' needs, which include, amongst others, machines for 25, 40, 50, and 60 cycles, to mention four of the most common frequencies; low, medium, and high voltages; normal and low temperature rises, etc.

Mr. Smith. Mr. S. P. SMITH (*in reply*): I have to thank the several speakers who have taken part in the discussion, and have shown such a lively interest in the non-salient pole type of machine. I am afraid, however, that, with one single exception, viz., Dr. Kahn, all the speakers have entirely failed to grasp the spirit of the paper. To any one who reads the paper carefully it must be at once clear that it was not my intention to compare this type of rotor with the well-known salient pole type, nor to advocate its use. The purpose of the present paper was to bring out a full description of the electrical properties, both good and bad, of the non-salient pole rotor, and this quite apart from its superiority or otherwise. Thus the discussion of the regulation, which most of the

speakers have brought very prominently to the front, is quite irrelevant, whilst Mr. A. M. Taylor most unjustly looks on the author as having "an axe to grind." Actually, however, the question of regulation no more belongs to this type of machine than to any other, and I merely introduced it in its logical order for the sake of completeness. Mr. H. W. Taylor even seems to think that I suggest a close regulation of 15 to 20 per cent. This also is entirely a misconception of my meaning, and it is no more my intention in the present paper to advocate a machine with close regulation than with coarse; the sole object of my notes on this point is to show how the output of the machine with a given open-circuit characteristic varies with the regulation. A similar relation can, of course, be deduced for the ordinary type of alternator. I must thank Dr. Kahn for the valuable points he has raised in the discussion. It is very gratifying to find that his experience has led him to the same conclusions for the best distribution of the rotor winding as those deduced in the paper. He has also clearly understood my object in introducing regulation, and although he thinks my conclusions are somewhat unfavourable to machines with coarse regulation, I think this is probably due to the fact that the curve in Fig. 12, on which I have based my deductions, is rather too good. Mr. Pensabene-Perez does not seem to agree with my method of treatment, which, according to him, "is built up on very rough and unstable ground, made up of assumptions and simplifications which are necessary for a general analytical treatment of an engineering character." I am not quite clear as to what Mr. Pensabene intends to convey by this rather general remark, but I take it he objects to the use of mathematics in dealing with the present problem. It is quite true that the simple trapezium curve has been assumed, which has necessitated neglecting the effect of the slots, as pointed out in the paper. That this small simplification, however, should make the whole investigation unreliable is absurd—first, because the presence of the slots in a case like that in Fig. 2 has very little effect on the *main* shape of the flux or the E.M.F. wave; and secondly, because in most modern designs magnetic wedges are used for closing the slots to avoid the prominence of any tooth ripple. Beyond this the investigation is just as accurate as that of any other engineering problem, and as for the long and tedious method he complains of, it need only be mentioned that it has to be done once for all, and its results are applicable generally. If, however, Mr. Pensabene has arrived at his pessimistic conclusions from the example he has sketched on the board I am not surprised, for he seems to have chosen the very worst case possible for the determination of the flux wave—indeed, it is questionable if anything but a rough-and-ready graphical method such as that used in salient pole type machines can be applied to such a case. Moreover, the characteristics of such a rotor winding as that described are certainly more like that of the salient pole type than of the non-salient pole, and I am quite prepared to believe that the adoption of such a peculiar system of winding with the largest coil at the centre of the pole, and the heating concentrated

Mr. Smith.

Mr. Smith. in a few very large slots, has few or no electrical advantages at all, and can only be justified for mechanical reasons. The objection made by Mr. H. W. Taylor that the method adopted in the present paper cannot be applied to every type of non-salient pole machine, has already been dealt with in the paper, where it is clearly pointed out that only the general case of the uniformly slotted rotor with a uniform air-gap and a partially distributed winding would be considered. Since almost every firm has its own peculiar method of constructing this type of rotor it is almost impossible, nor would it serve any useful purpose, to try to cover the whole ground. Further, Mr. Taylor's argument that the designer limits the short-circuit current to reduce the mechanical stresses on the winding in case of short-circuit is mere sophistry. Actually it is the output of the rotor that makes the ratio of short-circuit to full-load current less in a turbo than in a slow-speed alternator, for if this ratio were maintained the same in the former as in the latter, the output of the turbo would have to be considerably reduced. Thus it is primarily a commercial question, and not a technical one. The technical advantages are rather a result than a cause. Moreover, if the small short-circuit current is to be maintained when an automatic regulator is used, care must be taken that the exciting current is not increased when a short-circuit occurs.

JOURNAL

OF

The Institution of Electrical Engineers.

Founded 1871. *Incorporated* 1883.

VOL. 47.	1911.	NO. 210.

Proceedings of the Five Hundred and Twenty-Third Ordinary General Meeting of the Institution of Electrical Engineers, held on Thursday, May 11, 1911—Mr. W. DUDDELL, F.R.S., Vice-President, in the chair.

The minutes of the Ordinary General Meeting, held on May 4, 1911, were taken as read, and confirmed.

Messrs. W. C. Goodchild and H. F. D. Jacob were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected :—

ELECTIONS.

As Members.

Alphonse Reyrolle.
George Patrick Robertson.

As Associate Members.

Robert Brooks.
Herbert George Cakebread.
Clifford Corbridge.
Edward Denton.
Andrew Owen Gibbon.
Frank Herseè.
William Henry Hunstone.
Harry Richard E. Legge.
Arthur Samuel Markes.
Carl Munzel.
Eustace Savage Perrin.
William Davidson Ross.
Malcolm Chambers Timms.
Laurence Beddome Turner.
William Bryant Turner.

As Associates.

John Percival Forster.	Harold Edward Mortimer.
William Henry Lea.	Frederick Henley Ousey.

Harold Percy Wiggins.

A donation to the *Benevolent Fund* of £203 17s. 7d. was announced as having been received from the Trustees of the 1905 Olympia Electrical Exhibition, to whom the thanks of the meeting were unanimously accorded.

The following paper, "The Driving of Winding Engines by Induction Motors," by Mr. H. J. S. Heather (page 609), was read and discussed.

THE DRIVING OF WINDING ENGINES BY INDUCTION MOTORS.

By H. J. S. HEATHER, B.A., Member.

(*Paper received January* 2, 1911. *Read before* THE INSTITUTION *May* 11, 1911.)

For hoisting and winding work on a polyphase system of electric supply the direct application of the driving power of the induction motor has not hitherto been so general as its indirect application through the medium of continuous-current plant operated on the Ward-Leonard control system, with or without the Ilgner flywheel. It is not intended to give a description of the Ilgner system, the main object of which is to level down the peak load, an effect only necessary in cases where the supply is derived from small power stations. The principal causes which have prevented the adoption of the less costly direct induction motor drive have been, first, the losses arising from the waste of energy in the rheostatic control, which losses are avoided in the Ward-Leonard system; and secondly, the difficulties arising from the nature of the relations between torque, speed, and resistance in the secondary circuit of the induction motor.

Some tests carried out by the author on a 3-phase winder on the property of the Village Main Reef Gold Mining Company in 1906 convinced him that the first of these two objections was more or less groundless. The author then obtained figures for the over-all efficiency —that is, for the relation between the foot-pounds of useful work done in lifting rock in the shaft, and the input into the system (measured, of course, in kilowatt-hours), which compare on practically equal terms with the most satisfactory results that he has seen given for a converter system. It should be mentioned that in these tests the circumstances were unfavourable to the 3-phase plant, as the distance hauled through was short and the drive was through a reduction gear.

It is therefore with the second objection only that the author proposes to deal. It is obvious that if the control of the direct-coupled 3-phase motor can be made as safe and simple as that of the continuous-current motor of the Ward-Leonard set, the extra risk involved by the use of the continuous-current generator and the 3-phase motor driving it, as links in the chain of power supply, will be prevented, and the balance of security will be in favour of the direct 3-phase drive. In winding operations where men are raised and lowered security is the consideration of paramount importance.

It will accordingly be necessary in the first place to investigate wherein lies the acknowledged simplicity of the Ward-Leonard control. In this system there is a continuous-current winding motor in which the field strength is of constant value, being derived from a separate source of supply and of fixed direction. The current passing through the armature of the motor is adjustable both in value and direction. This result is secured by regulation and reversal of the field of the continuous-current generator, the armature of which is connected to that of the winding motor. This continuous-current generator is driven at practically constant speed by a motor connected to the main power supply system. The result of these arrangements is that the torque exerted by the winding motor is proportional to the current passing through its armature, and a reversal of this current causes a reversal of the direction of the motor torque. When the torque is in the direction of the winding motor's motion the motor is putting out mechanical work, but when the torque is opposing the motion, as in braking or in lowering a load more slowly than it would fall under the action of gravity, the winding motor changes its function and becomes a generator, driving as a motor the machine which under the former circumstances had been acting as a generator. The motor connected to the supply mains now also reverses its function and becomes a generator, forcing into the supply mains electric power derived from the descending load in the operation of braking. The control is therefore regenerative, and it becomes possible to utilise a large proportion of the power which would otherwise be wasted.

The method of control above described is usually effected by the shifting of an ordinary starting lever backwards or forwards from a central position. When the lever is in the central position no current is supplied to the field magnets of the continuous-current generator from the separate exciting machine. When the lever is moved more or less forward, more or less current in one direction is supplied to these magnets. A greater or less electromotive force is then produced in the armature, which, as before mentioned, rotates at a constant speed. If the winding motor is at rest, and so, in spite of being constantly excited, is producing no electromotive force, the generator electromotive force drives a current through the motor armature, producing a torque which, if large enough, starts the motor. The back electromotive force then produced tends to reduce the current and the torque, and to keep this latter at a constant value more and more current has to be sent through the generator field windings, this being effected by a further movement of the regulating lever.

A backward movement of the lever will at any moment reduce or reverse this torque, the latter bringing into play the regenerative action above referred to.

It will be seen that this method of control is of the utmost simplicity, and that it has the very great advantage of being regenerative in its action.

As regards the question of simplicity, the main points to be noted are :—

1. That the electrical operations carried out by the movement of the control lever are the cutting in or out of the resistances in the circuit of the generator field magnets and the reversing of the connections with the exciter busbars.
2. That a movement of the lever in one direction tends to increase the torque of the winding motor in a direction which may be called the positive direction of rotation, whilst a movement of the lever in the opposite direction tends to decrease the torque of the winding motor in the positive direction of rotation. If it is borne in mind that a torque in the positive direction when decreased to a value below zero becomes a torque in the negative direction, the above statement covers the whole of the relation between the movement of the regulating lever and the torque of the winding motor. It must, however, not be forgotten that a variation in speed, with a fixed position of the control lever, will cause a change in current and torque owing to the variation of the electromotive force produced by the constantly excited winding motor. This, of course, happens when the torque applied is either more than sufficient or less than sufficient to produce motion with uniform velocity.
3. That to a definite torque corresponds a definite value of the current flowing in the armatures, so that a polarised ammeter always affords an indication of the amount and direction of the torque. The torque so indicated is entirely independent of the speed at the moment, and the curve showing the relation between current and torque is a straight line if armature reaction is small enough to be neglected. The ammeter consequently can be, and in practice actually is, used by the engine-driver as a torque indicator, though it is not known by this name.

Although it is a point that is not being dealt with at present, it should be noted in passing that regenerative action is inherent in this method of control, and accordingly introduces no complications of any sort. In fact, if the regenerative action becomes inoperative or partially inoperative, as, for instance, in the case of the opening of the main circuit breaker forming the connection to the supply mains, the method of control becomes unworkable as regards both driving and electrical braking.

With all continuous-current machinery the question of speed depends upon the voltage, which may be regulated in two ways. One way is that described above, by regulating the field strength, and the other is by absorbing more or less of the available voltage of supply in resistances. The wastefulness of the latter method, usually

called the rheostatic method of control, is obvious and well known. In simplicity it compares on equal terms with the other, the electrical operations being identical, but as they affect the main instead of a field circuit, the scale on which they are conducted is larger.

With induction motors the only simple method of speed control, that of inserting resistance into the secondary circuit, is comparable when lifting, so far as wastefulness is concerned, with the rheostatic control of continuous-current motors. In each case a definite torque at a speed between full speed and zero can only be secured by using the full power that would correspond to it at full speed. In the case of the continuous-current motor the difference between the full speed power and that corresponding to the speed desired is dissipated as heat in a series resistance; in the induction motor the difference appears as electrical output of the secondary member of the motor, that is, usually, the rotor, and is then ordinarily converted into heat in an external resistance.

Both in simplicity of operation and wastefulness, therefore, the induction motor and the rheostatically controlled continuous-current motor are on a level when lifting at speeds below full speed.

When lowering loads at speeds below full speed the continuous-current motor can be operated with rheostatic control in two ways. The more economical is to cut off the supply of current to the motor armature and allow the motor to operate as a generator, which it is capable of doing at all speeds, absorbing in the resistance the whole of the power generated. The power derived from the mains during this operation is only that required for excitation. The complication, however, of switching off the mains from the motor armature and short-circuiting it through the resistance is introduced, and it becomes necessary to reverse both these movements to bring the motor absolutely and steadily to rest by electrical means.

The alternative method, more wasteful in power, but simpler in operation, is to leave the motor connected to the mains, to take from them the current corresponding to the desired motor torque, and to absorb in the resistance both the power represented by this current and that produced by the hoisting motor, now operating as a generator driven by the descending load. Since at full lowering speed the winding motor voltage (if the machine may still be called a motor when operating as a generator) will be about equal to the line voltage, the resistance has to be large enough to absorb about twice the full normal output of the motor.

The action of the induction motor when lowering loads may be considered as almost exactly similar to the latter of the above described actions of the rheostatically controlled continuous-current motor. It is equally simple and equally wasteful.

Both for lifting and lowering loads, therefore, it may be said that just as in the Ward-Leonard system the electrical operations involved are the cutting in and out of resistances in the circuit of the generator fields and reversing them, so exactly the same operations in the motor

armature circuit will give complete rheostatic control of a continuous-current motor, and the cutting in and out of resistances in the secondary circuit of an induction motor combined with the reversing of the primary connections will give an equally simple method of induction motor control. Equally simple methods of winding engine motor control being therefore available, it follows that the direct induction motor drive must usually have by far the best over-all simplicity, as practically all heavy transmission work is done on the 3-phase system, and consequently whenever continuous - current motors are employed some form of converter is a necessary additional complication.

In order to show that the foregoing remarks on the simplicity of induction motor control are justifiable, a few explanations and diagrams may be necessary. Both the properties of the induction motor and the requirements of winding operations require looking into.

The ordinary induction motor with no added resistance in the secondary circuit presents a torque-slip curve similar to that shown in curve 1

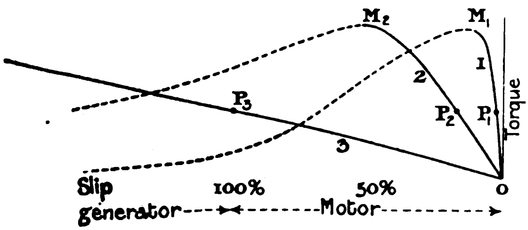


FIG. 1.

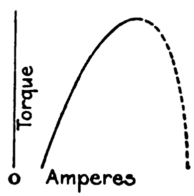


FIG. 2.

Fig. 1. This curve, it will be noticed, is extended beyond the point corresponding to 100 per cent. slip—that is, beyond the point corresponding to standstill—in other words, into the region of the reverse direction of motion. M_1 is the point at which the torque has its maximum value, and P_1 may be taken as that of normal full load. The effect of adding external resistance to the rotor or secondary circuit will be to stretch out this curve in the horizontal direction. The new curve will start as before, with zero torque at zero slip ; the maximum torque, which remains unaltered whether external resistance is added or not, and the normal full-load torque, will be obtained at higher slips than before. Such a curve is shown in curve 2 in Fig. 1.

Adding further resistance stretches the curve still further in a horizontal direction. In curve 3, for instance, the full normal torque is got at standstill. With the amount of added resistance that corresponds to this curve, the motor would just hold a load giving a torque equal to full-load torque without moving it in either direction. With a still larger resistance this torque would only be obtained at a backward speed. Any number of such curves can be obtained by suitably choosing the resistance to be used, and of course changing the

resistance will at any moment transfer the representation of the operation of the machine from one to another of the curves. Consequently any torque whatever, so long as it is less than the maximum torque of which the motor is capable, can be obtained at any slip greater than the slip corresponding to that for maximum torque with the rotor short-circuited. With slips smaller than this, only torques less than the maximum can be obtained. With these limitations, therefore, any torque can be obtained at any speed forward or backward, and complete control of the induction motor at all speeds is theoretically possible.

It will be well to consider in some detail the nature of the actions which lead to this result. At slips between the values of zero and 100 per cent. the induction machine operates as a motor, the torque derived from the electrical supply being exerted in the same direction as that of rotation. At slips less than zero, or negative slips—that is, at speeds above synchronous speed—the electrically supplied torque reverses its sign, and consequently is opposed in direction to the rotation, and the machine becomes a generator. Mechanical power is absorbed in the rotor; wattless magnetising current is taken into the stator from the mains, and a power current passes from the stator into the mains. At slips greater than 100 per cent. the electrically supplied torque, as may clearly be seen from the torque-slip curves given in Fig. 1, retains the same sign as it had during the range of motor action of the machine, but since 100 per cent. slip is equivalent to zero speed, the direction of rotation at this point changes sign, and again the directions of the electrically supplied torque and of the rotation are opposed, and again the machine operates as a generator. Mechanical power is consequently again absorbed by the rotor, but electrical power, and not only wattless magnetising current as in the case of over-synchronous speed, is derived from the mains. The fact that mechanical power can be absorbed by the rotor obviously makes it possible to use the machine as a brake; there is further no limit to the speed at which this braking action can be obtained, for, as the curve 3 of Fig. 1 shows, full normal torque (or any torque up to the maximum of which the motor is capable) can be got at zero speed.

When the direction of rotation is reversed (or with the same direction of physical rotation, when the direction of rotation of the field is reversed), the machine is taking in both electrical and mechanical power. What becomes of this power is easily seen from the consideration that the induction motor is a particular instance of an alternating-current transformer. At full speed and full-load torque its output as a transformer is zero, the rotor slip-rings being then short-circuited; the output as a motor is the full-load output. At zero speed, the torque remaining the same, the electrical input is unaltered, for corresponding to all the infinite number of torque-speed curves which may be shown as in Fig. 1, there is one and only one torque-ampere curve, and for each value of the amperes there is only one value of the power factor. This torque-ampere curve is

shown in Fig. 2, torque being again plotted vertically, but amperes, instead of slip, horizontally. At zero speed, the electrical input being the same, the output as a motor is zero, and the output as transformer is the input less the losses. The frequency of the current forming the output is at standstill the same as the primary frequency, and the output is absorbed in the external resistances connecting the slip-rings. At speeds intermediate between full speed and standstill the machine operates partly as motor and partly as transformer, the proportion of the total output that appears in the form of transformer output increasing uniformly from zero at full speed to unity at standstill. The transformer output is at a frequency having the slip ratio to the primary frequency. This output consequently cannot be returned to the mains and is ordinarily absorbed in the resistances across the slip-rings and dissipated as heat. At reverse speeds the whole electrical input is converted into transformer output, and in addition the work corresponding to the descent of the load is converted into eletrical energy, which makes its appearance as rotor electrical output. If the speed of lowering is full speed backwards, the total combined output of the rotor, taking into consideration both its transformer and generator functions, and on the assumption that all efficiencies are 100 per cent., is twice the input that would be required to lift the same load at full speed. All this electrical output would be in the form of current having twice the frequency of the supply current and would have to be wasted. As much electrical power has to be used to lower the load at this, or any other speed, as to raise it (still assuming 100 per cent. efficiency), and the resistances have to be large enough to dissipate twice this amount. The generator action of the machine, though useful for electrical braking, effects no saving in the power consumed.

The circumstances are therefore practically equivalent to those holding good in the method of working with continuous-current plant, where the motor is kept constantly connected to the supply mains and the resistance has to be made large enough to absorb both the normal load of the motor and its output as a generator driven by the descending load.

The ordinary requirements of winding include both the raising and lowering of loads, and in each case there are in every trip three periods if the operation is carried out correctly. These are the period of acceleration, the period of full speed, and the period of retardation. Assuming, then, the simplest case, that in which the acceleration and retardation are uniform (though in ordinary practice the rate of change of speed is not usually uniform but decreases gradually to zero), the velocity-time diagram will be of the shape shown in Fig. 3.

This diagram may be taken as applying to both lifting and lowering the load, or if it is preferred to use the positive or negative signs for velocity according to the direction of motion, the above diagram may be considered as the lifting diagram, and its reproduction below the line of zero velocity as the lowering diagram.

During the period of lifting at uniform velocity the work required to be done by the motor is that corresponding to the actual foot-pounds of energy represented by the lifting of the load through a certain distance plus the work wasted in friction, including not only the friction in the surface machinery but that arising from the travelling of the loaded skip in the shaft. It is assumed that air resistance to this moving load is small enough to be neglected. The torque developed by the motor is that which corresponds to this total work at the full speed corresponding to the uniform velocity. If the system is supposed to be balanced so far as the ropes are concerned (that is, if a tail-rope is used equal in weight to the head-rope), there is no variation in the effective length of the suspended ropes, and the torque and power will be uniform throughout the period of uniform velocity. This simplest case will be the one considered.

If it is required merely to suspend and not to lift the load, there is no friction to overcome, but with the exception of this friction loss, the motor will be called upon to develop the same torque as that needed

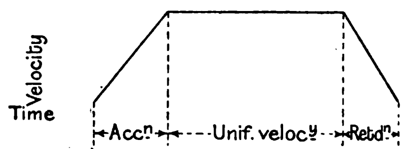


FIG. 3.

for the full-speed run in spite of the fact that the motor would be doing no work.

During the acceleration period the total torque will be that corresponding to the suspending of the load, plus that needed to overcome friction, plus that necessary to impart to the system the full speed in the desired time. With uniform acceleration and balanced ropes, this total torque would not vary during acceleration. It would, however, be greater than that required during the period of uniform velocity. The mechanical power required would increase uniformly from zero at the moment of starting to a maximum at the point of attaining full speed, at which point the power, like the torque, would suddenly drop to that corresponding to the uniform velocity.

During the period of retardation (assuming this also to be uniform) three different cases might arise. In the first the ascending load might be allowed to come to rest under the action of gravity and friction. In this case the motor would not be required to exert further torque nor to give out further power; it could be entirely disconnected from the mains. In the second case a uniform torque might be used, less than that required to maintain uniform velocity, and the load would come to rest in a time longer than if gravity and friction alone had effected the retardation. During the operation

of such a torque the power given out would uniformly decrease from a maximum less than that required at uniform velocity to a minimum at zero. In the third case, which is the one ordinarily

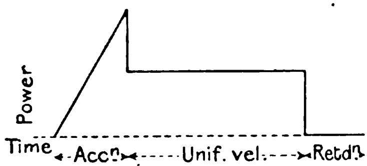


FIG. 4.

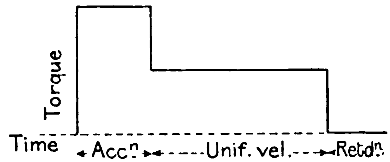


FIG. 7.

occurring in practice owing to its being desirable to bring the load to rest in a time shorter than that in which gravity and friction would do so, a reverse torque would have to be employed which might

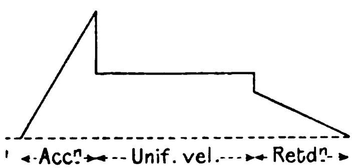


FIG. 5.

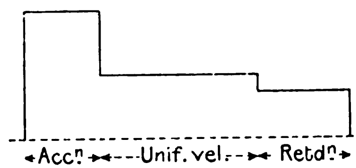


FIG. 8.

have any value according to the time allowed for retardation; the power which in this case would have to be absorbed, would uniformly decrease from a maximum greater than that corresponding to the uniform velocity to a minimum at zero.

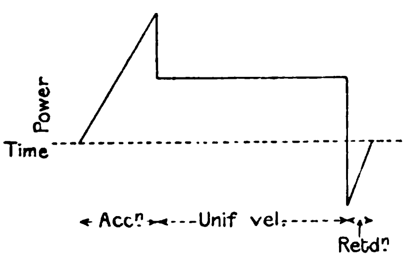


FIG. 6.

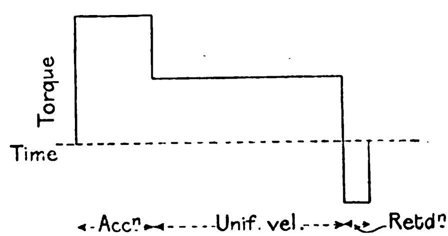


FIG. 9.

For lifting, therefore, the power-time diagram corresponding to the velocity-time diagram of Fig. 3 would be similar to those shown in Figs. 4, 5, and 6, according as the first, second, or third cases held good for the retardation period.

The torque-time diagrams under the same conditions would be as shown in Figs. 7, 8, and 9.

It must be remembered in each case that the power or torque due to friction must be taken into account, and the proper sign must be given to it as it increases the power or torque required from the motor or decreases it when the motor is acting as a braking generator.

It has already been pointed out that the torque required to suspend a load without moving it would be the same as that required to raise it at full speed less that absorbed at that speed by friction. Consequently the torque required to allow the load to descend at full speed, that is, to prevent its accelerating under gravity, is the above-mentioned suspending torque less the friction torque, and so is the same as the lifting torque less twice the friction torque. If a uniform torque, smaller than the torque needed to lower at uniform speed, is applied, the load will accelerate uniformly, and conversely to bring the load to rest at the end of the trip, a larger torque than that needed to lower at full speed is required. There will not here be three cases to consider for the retardation, for this can only be effected by offering

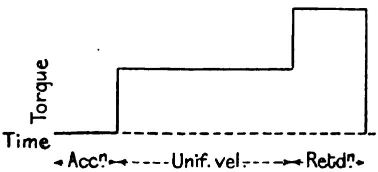


FIG. 10.

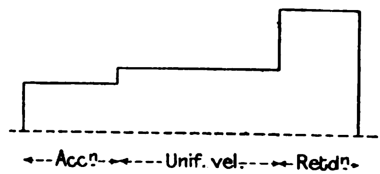


FIG. 11.

an opposing torque to that derived from gravity, and the only question is as to the magnitude of the retarding torque to be used, which, of course, depends upon the time that can be allowed for retardation. Corresponding, however, to the three cases of retardation of an ascending load there might be three cases of the acceleration of a descending load. In the first, the load might be allowed to fall under the action of gravity and friction, retarded only by the inertia of the moving parts; in the second, a retarding torque might be used so as to reduce the effect of gravity; and in the third, an accelerating torque might be used to assist gravity. The three torque-time diagrams for thus lowering the load would then be as shown in Figs. 10, 11, and 12. It is, of course, to be kept in mind that the torque needed for lowering a load at uniform speed is in the same direction as that for lifting the load. The power, however, is not of the same sign owing to the reversed direction of motion. The three power-time diagrams corresponding to Figs. 10, 11, and 12 are accordingly like those shown in Figs. 13, 14, and 15.

The author feels that some apology is necessary for going over ground that must to many be already well trodden, but in instituting a comparison between winding under the Ward-Leonard system and

the direct-induction motor drive it is absolutely necessary to get a clear idea as to the mechanics of the proposition to be dealt with. The circumstances assumed are the simplest possible—in fact, they are simpler than any that occur in practice, for although it is sometimes

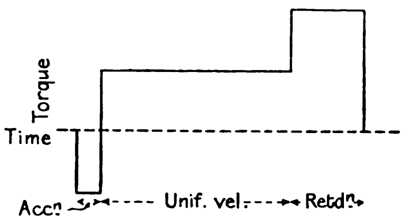


FIG. 12.

feasible to have the ropes balanced, this is very often not the case; acceleration and retardation are never uniform, and the problem is generally complicated to some extent by the use of conical or cylindro-conical drums, or flat rope reels. The modifications thus introduced,

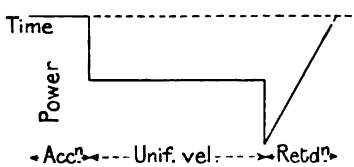


FIG. 13.

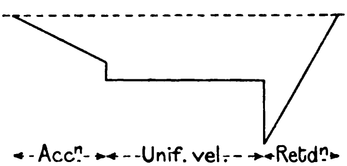


FIG. 14.

although they frequently involve reversing moments, are merely matters of detail. Enough has, it is hoped, been said to show that if mechanical brakes are supposed not to be relied upon, and all control has to be effected electrically, the operation of a winding

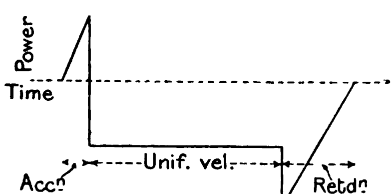


FIG. 15.

engine demands the possibility of getting any torque in either direction at any speed in either direction, subject, of course, to the limitations imposed by a maximum torque and a maximum allowable rope speed.

The fulfilment of these requirements, as has already been shown, is equally possible by either the Ward-Leonard or the direct-induction motor drive.

The diagrams above given show the power input and the torque input as measured at the winding drums. To ascertain from them what the power bill will amount to it is necessary to construct diagrams for the power taken from the mains.

In the case of a system like the Ward-Leonard, in which regeneration can be brought into play at all speeds of the winding motor, this process of construction must begin at the power-time diagram. For lifting in practical work the most usual form of power-time diagram, which is also (as will appear later) the most unfavourable to the induction motor drive, is that shown in Fig. 6. Braking being assumed to be done electrically, the regenerative action of the Ward-Leonard system comes into operation where the power changes sign. In order to arrive at the diagram for the power taken from the mains, the ordinate corresponding to every point for which the power is above the zero line has to be divided by a fraction representing the combined efficiencies (1) of the winding motor at its instantaneous speed and ampere load, (2) of the continuous-current generator at approximately full speed and at its instantaneous load, and (3) of the motor of the converter set at the same speed and its instantaneous load. When regeneration takes place, the power returned to the mains is got by multiplying each power ordinate by a corresponding fraction. The result is, of course, to increase considerably the portion of the diagram above the zero line, representing power taken, and to decrease the portion below the zero line representing power returned.

Suppose now, after an interval of standstill, an equivalent load has to be lowered, as often happens when men are being lowered. The diagram most generally followed would be that of Fig. 14, in which a controlling torque is always kept on the drums during the whole of the trip. This diagram has to be treated, in order to get at the amount of energy returned to the mains, in the same way as was used for the braking period of the lifting—that is, it has to be multiplied by an efficiency fraction. This trip will again be followed by a period of standstill, and throughout this, as in the former interval of standstill, the no-load losses of the induction motor, and part of the excitation losses of the continuous-current plant, are going on.

The power consumption diagram for the pair of trips, one up and the other down, will therefore be somewhat similar to that shown in Fig. 16, where, for the sake of comparison, the power giving into and coming out of the winding drums is shown in dotted lines.

To get the corresponding power consumption diagram for the direct-driving induction motor, the action of the motor under reverse current and at speeds below full speed must be kept in mind. The power consumption diagram will in consequence be derived from the torque-time diagram, but the reversal of the direction of the torque does not mean the return of power to the mains. The power derived

from the mains corresponding to any torque is now independent of the speed, and even of the direction in which that torque is exerted, and the power taken from the mains is determined by dividing, by the fraction representing the efficiency of the motor at the instantaneous speed and ampere load, the power that would be put into the winding drums at full speed, and adding thereto, for the lowering trip, the power that would be given out by the winding drums at full speed multiplied by the corresponding fractions for efficiency. The full line in Fig. 17 may be taken as showing the power taken from the mains during a lifting and a lowering trip separated by an interval, the dotted line being the power put into and taken out of the drums. It must not be forgotten that, both in Fig. 16 and in Fig. 17, the whole of the operations are supposed to be carried out electrically, no mechanical brakes at all being used.

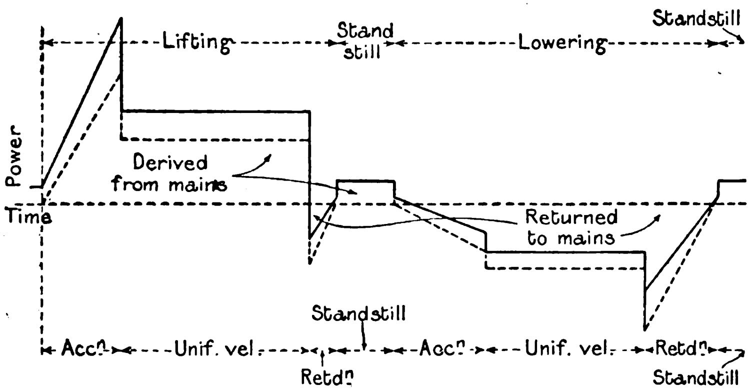


FIG. 16.

This accounts for the high power consumption of the induction motor during the period of standstill.

There will be very little chance that the energy taken by the induction motor for such a pair of trips, the one raising and the other lowering a load, will be less than that taken by the Ward-Leonard arrangement to effect the same operation. If, however, the number of times that loads have to be lowered is small, and if the length of trip is long, and the interval between trips long, and mechanical brakes are allowed to hold the load at rest, it is quite possible for the direct-driving induction motor by its economy on the uniform speed portion of the trip, and when standing still, to do more than make up for its extravagance in power when starting and stopping.

It should be noted that the long duration of the acceleration peak when lifting is an important disadvantage when the supply is obtained from a small power station. Another point worthy of notice is the

large amount of energy that the controlling resistance of the induction motor has to be capable of taking up. In Fig. 17 it would be represented by the area enclosed between the full line, which shows the power being taken from the mains and the dotted line which shows that being put into and taken out of the winding drums. This area would be reduced only by the losses in the winding motor whether operating as motor or generator. During the lowering trip this energy will approach twice the value of that which the motor is capable of taking in. The dissipation of this large amount of energy in the case of a big winder need, however, present no difficulty in practice to the mechanical engineer, who is accustomed to deal with a similar problem on a similar scale when he runs his steam engines on condensers.

There are, of course, several ways of avoiding this loss in lowering. For instance, it may be permissible to allow a slightly higher speed

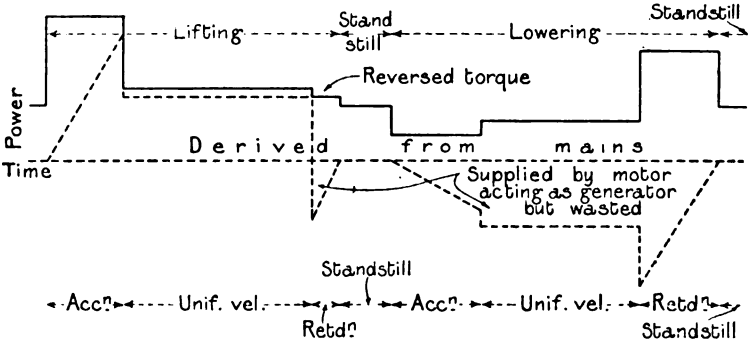


FIG. 17.

when lowering, so that the induction motor running above synchronous speed may act as a generator returning power to the mains, or a similar result may be attained at a lower speed by using a two-speed motor. Both these methods entail complications in the manipulation of the controlling lever, and the writer prefers to pin his faith to the simpler process of using reverse current and to face the losses. As indicated above, these can easily be dealt with even if large, and when there is not much lowering to do they very often are unimportant.

Apart from the question of economy, the chief argument that is brought forward by the advocates of the Ward-Leonard system against the direct induction motor drive is that it is difficult for the driver to tell at any time whether he has to increase or to decrease the resistance in the secondary circuit in order, say, to increase the torque. This difficulty arises from the falling off of the torque-slip curve at high values of the slip (see Fig. 1). There is, however, an extremely simple way of getting an absolutely certain guide to this. It is to

use an ammeter as a torque indicator in exactly the same way as is done in the Ward-Leonard system.

To see the reason why this simple method can be applied, it is necessary to return to the torque-slip curves of Fig. 1. As has already been explained, the transitions from curve 1 to curve 2 and from curve 2 to curve 3 are effected by adding resistance to the rotor circuit. Let it be supposed that at any particular moment the amount of external resistance in the rotor circuit is such that the motor is giving the torque-slip curve shown as 2. So long as the speed is such that the portion of the curve being worked on is that portion lying between the point of maximum torque M_2 and that of synchronous speed O, that is the portion of the curve that is shown in full line in Fig. 1, the addition of any small amount of resistance will cause the curve of operation to move away from the curve 2 toward the curve 3. No large instantaneous variation of the speed being possible, there would be an instantaneous reduction in the value of the torque at that speed, for at any given speed the full-line portion of the curve 2 lies above the full-line portion of the curve 3. Similarly an instantaneous reduction of the amount of resistance in the rotor circuit will cause the curve to move away from the curve 2 toward the curve 1, and so long as the full-line portions of the curves are again worked on, an instantaneous increase in the value of the torque takes place. So long, therefore, as work is limited to the full-line portions of the curves, an increase of resistance always reduces the torque and a decrease of resistance always raises it, and no uncertainty can possibly arise.

The case is quite different if the motor is ever allowed to get on to the dotted portions of the curves; for instance, the dotted portion of curve 1 lies below curve 2 at low speeds and above it at high speeds, and at very low speeds it even lies below curve 3, so that an increase of resistance might or might not then produce an increase of torque, and a great deal of dangerous uncertainty would arise. But since there is no uncertainty on the full-line portions of the curves, it is clear that all uncertainty can be eliminated if it can be ensured that the full-line portions of the curves shall be the only portions on which work is allowed to be carried on.

The way in which this certainty can be reached is by the ammeter readings. As already mentioned, to all possible torque-speed curves there is only one torque-ampere curve, as shown in Fig. 2. This curve shows that the amperes go on increasing from the point of zero torque, when the amperes are the no-load current of the machine, to the point of maximum torque, and that even after this is reached, though the torque begins to diminish, the amperes continue to increase, reaching their maximum value (which, it may be mentioned, is in the neighbourhood of $\sqrt{2}$ times the value at maximum torque) only when the slip is infinite, that is, when an infinite backward speed is reached, by which time the torque has again become zero. In order to make this clear the torque-ampere curve is shown in two portions, a full-line portion corresponding to the full-line parts of all the torque-slip curves of

Fig. 1, and a dotted portion corresponding to the dotted parts of the torque-slip curves. It can, therefore, be absolutely ensured that the full-line portions of the torque-slip curves are always being worked to, by making certain that the full-line portion of the torque-ampere curve is being worked to, and, as the shape of the curve shows, this simply means that the amperes must not be allowed to exceed a certain maximum value, which can readily be fixed once for all for any individual motor.

In practice, a reasonable margin would be allowed to cover inequalities in the voltage of supply, etc., and the driver would be instructed never to allow the amperes to exceed the lower value so decided upon.

So far as driving in one direction is concerned, therefore, the simplicity of the control of the direct-driving induction motor is brought exactly level with that of the continuous-current motor of the Ward-Leonard system. The fact that in the latter case the torque-ampere curve is more nearly a straight line than in the former does not affect the matter in the least, as it is in both cases an indication, not of current but of torque, that is really needed, and there is no necessity for the scale to be uniform.

But the polarised ammeter ordinarily used in the Ward-Leonard control goes farther than merely to show the approximate value of the torque; it indicates also the direction, and this is undoubtedly useful. A similar result can be arrived at very simply and at very small cost for the induction motor drive. With the induction motor drive a reversal of the direction of the torque can only be obtained by reversing the direction of rotation of the field in the stator. This can be, and usually is done, by the movement of the same lever that inserts or cuts out resistance in the rotor circuit, and it is easy to make this lever, at the same time that it reverses the stator field, put into circuit a second ammeter coil which deflects the common needle in a direction opposite to that which the first ammeter coil gives it.

The description of the relation between torque, speed, and rotor resistance may seem somewhat complicated, but the practical effect is perfectly familiar to any one who has had experience with induction motors. The rapid falling off of the torque when an overload has brought the motor speed down below the point at which maximum torque is got with a fixed rotor resistance is a very well-known phenomenon. It is certainly not one that can logically be brought forward by the advocates of the Ward-Leonard system as an argument against the use of the direct-driving induction motor for winding engines. If it is any argument at all it applies with equal force to the majority of Ward-Leonard equipments, for it is usual for the generator of these to be driven by an induction motor, and it is possible by making a large demand for power upon the generator to overstep the pull-out torque of the driving motor and cause it to stop. It is usual with manufacturers, in order

to avoid this risk, to make the induction motor excessively large, which does not improve either its efficiency or its power factor at normal loads.

With a double ammeter as above described the watching of the control of winding operations carried on by a direct-driving induction motor becomes as simple as in the case of a Ward-Leonard control. If proper attention is paid to safety it becomes simpler, for, in order to avoid the risk of exceeding the pull-out torque of the induction motor driving the generator of a Ward-Leonard set, it would be necessary to have some arrangement to indicate when this torque was nearly reached. The simplest arrangement which the writer knows of is the ammeter which he suggests using for the direct induction motor drive.

This would involve equipping the Ward-Leonard gear with an alternating-current ammeter in addition to the polarised one in the continuous-current circuit. This would be confusing, but would undoubtedly be cheaper than the present expedient of putting in an induction motor so large that it is practically impossible for its maximum torque to be exceeded. It may further be pointed out that there is not very much reason against adopting the same expedient with the direct induction motor drive.

It will be seen that the guide afforded to the driver of the winding engine with the direct induction motor drive is, under the author's arrangements, almost exactly similar to that which the driver of a Ward-Leonard set has to rely on. The similarity, however, extends farther than this: the necessary movements of the control lever are almost precisely similar in kind, though not in extent. If the double trip, once lifting and once lowering, be considered, the movements of the lever necessary to secure this with the Ward-Leonard may be plotted as shown in Fig. 18. Here time is again plotted horizontally, and the position of the control lever at any moment, forward of, or behind, the central position, is shown by the length of the ordinate above or below a zero line. No attempt has been made to give quantitative values, but the nature of each movement required can be gathered from such a diagram, which corresponds to the power diagram of Fig. 16. In Fig. 18 the first, sloping, part of the diagram shows a gradual forward movement of the lever during acceleration when lifting. There is then, theoretically, on the assumption that the acceleration ceases suddenly, a backward movement followed by a period during which the lever remains stationary and the velocity is uniform. There is then a quick backward movement to call into play the generator action of the motor for braking, and during the retardation the lever has to be gradually brought further back until, if the retardation is uniform, the zero is passed. A sudden move forward would then give enough torque to hold the load balanced.

To start lowering, this torque is suddenly reduced by a backward movement, which continues gradually during the acceleration. To stop the acceleration more current must be allowed to pass, and a sudden forward movement is needed to weaken the field of the generator now

a motor. This is followed by a stationary period during constant velocity, and then comes a sudden forward movement allowing the driving motor (now a generator) to produce more current and begin to slow down, which process is completed by a gradual forward movement past the position at which a balance is reached, to which a return is made the moment the load has come to rest.

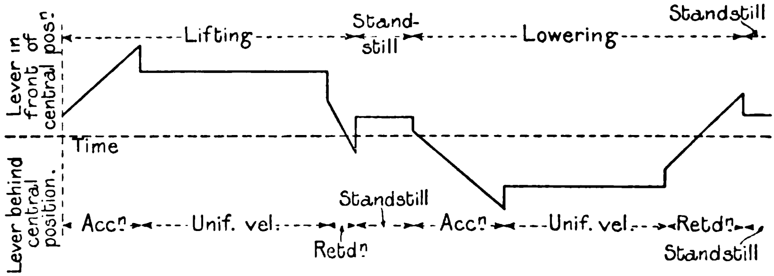


FIG. 18.

The corresponding diagram for the induction motor drive is shown in Fig. 19, which corresponds to the power diagram of Fig. 17. Here again the first sloping part of the diagram shows a gradual shifting forward of the lever during acceleration when lifting. If, as is ordinarily the case, the full-speed part of the run is done with all resistance as far as possible cut out of the rotor circuit, the peak in the

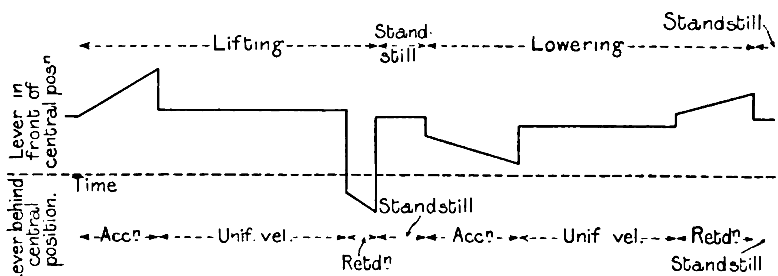


FIG. 19.

diagram before returning to the uniform velocity portion would be non-existent. The lever is then held stationary during the time of uniform velocity; it is then moved quickly backwards beyond the point at which zero is passed and stator reversal is effected, with a continued backward gradual movement during retardation until rest is reached, when a rapid forward movement has to be made to arrive at the torque necessary for balancing. To start lowering, the torque is suddenly reduced by a backward movement, which is continued gradually throughout the acceleration, but does not extend so far as

the zero position. There is then a quick return forward nearly as far as the balancing position during the time of uniform velocity, then a forward movement increasing the torque to get the retardation, the movement continuing gradually until rest is reached, when there is a sudden return to the balancing position.

It must not be forgotten that throughout these diagrams acceleration and retardation have been assumed to be uniform, and consequently they begin and end suddenly. The result of this assumption not being true in practice would be that all angles in the diagrams, and particularly the peaks, would be rounded off. A further modification of the last diagram, owing to the fact that all resistance is usually cut out when lifting at uniform velocity with an induction motor, has already been referred to, and would result in levelling down any peaks that are shown as rising above the line of lifting at uniform velocity.

In comparing Fig. 19 with Fig. 18 there are two points to notice. The first is that exactly similar movements, so far as direction is concerned, are required under both systems at every stage of both lifting and lowering. Sometimes in the one case, and sometimes in the other, one of the movements has to be carried over a wider range. It cannot be contended that the direct induction motor drive introduces any complication. The second point is that when lowering a load with the induction motor drive a forward position of the lever is required throughout. In this respect the duties of the driver of the induction motor agree quite closely with those for raising and lowering with steam and without using mechanical brakes, and this might properly be used as an argument in favour of the direct-driving induction motor where the problem is one of conversion from steam to electric driving. The author, however, does not attach any importance to this, as in his experience drivers accustomed to steam and put on to electric driving have, in a few days, invariably preferred the electric control, whether on the Ward-Leonard or the direct-driving induction motor system.

It should be pointed out that the cycle of operations depicted in the diagrams above, *i.e.*, lowering a load immediately after lifting one, is not the cycle that usually has to be carried out in practice. Ordinarily there is a succession of trips, all lifting loads, first with the one drum and then with the other. Such a succession of trips may be followed by a series of lowering trips. The diagrams are given in the form shown in order to cover both sets of operations. A reflection of the two lever-operating diagrams, Figs. 18 and 19, in the zero line gives the corresponding operations for the other drum.

A note may be added as to the provision of an emergency safety arrangement in case of a failure of supply from the 3-phase mains. It is clear that ordinarily, if this were to happen with the induction motor drive, the driver would be rendered helpless except for his mechanical brakes, and a serious position might arise if a load were being lowered at the moment of failure unless these mechanical brakes were absolutely reliable. Except for the small additional

safeguard supplied by the inertia of the converter set, the same thing is true with the Ward-Leonard system, if, as is usually the case, the source of supply is a 3-phase one. Of course, if the Ilgner flywheel is added the large flywheel inertia is a solid protection.

It was pointed out some years ago that electric braking could easily be obtained on an induction motor by exciting either stator or rotor with continuous current. There are several different ways in which this can be done, using one, two, or all three of the phases of the ordinary 3-phase motor. The possibilities of this proposal do not, however, appear to have been recognised at that time, and nothing much appears to have been done with it owing to the failure to discover any satisfactory method of control.

The suggestions thrown out by the author supply such a method. The source of continuous-current supply can be made of such a voltage that the primary field strength produced by the current it sends through the stator will be equal to that produced by the alternating current corresponding to the maximum torque. Even if applied to the stator this will only require quite a low voltage, as the opposition to the current flowing in an induction motor stator comes mainly from the inductance and not from the resistance of the circuit. The effect of the time constant, after the failure of supply, is not so great as to form an insuperable obstacle. It is possible with a moderate continuous voltage to get, within a fraction of a second, a stationary field from the stator equivalent to that required when the rotor current corresponds to maximum torque. The continuous current thus sent through the stator will probably have a dangerously high heating effect if kept on for any length of time, but an emergency device on a winding engine has to do its work in a very few seconds if it is to be of any practical use. The effect of this stationary field in place of the normal rotating one is to convert the induction motor into a synchronous generator capable of absorbing at any particular value of its absolute speed the same torque that it could deal with as an induction generator at the same relative speed above synchronism. The torque-slip curves of Fig. 1 (which by reversing the sign of the slip apply to the induction generator) thus become torque-speed curves, and the torque-ampere curve of Fig. 2, though no longer applicable to the stator current which is now constant and continuous, does apply to the rotor current.

A point here arises which must not be overlooked. The continuous current passing through the stator having a constant value, and that value being such as to give the proper resultant field strength when the rotor current corresponds to maximum torque, it follows that when the rotor current is less than this the resultant field strength, with continuous-current excitation, will be stronger than that of the normally operated induction generator; also that at rotor currents greater than that corresponding to maximum torque the resultant field strength will be weaker than that of the induction generator. As the torques in all cases depend upon the resultant field strengths, it follows that when

the torque-slip curves of Fig. 1 and the torque-ampere curve of Fig. 2 are converted respectively into torque-speed curves and a torque-ampere curve for the continuous-current excited braking generator, the full-line parts of the new curves lie above those of the old ones, and their dotted parts lie below those of the old ones, the maximum torque points being always unaltered. If, therefore, the full-line ampere values only are worked upon, the torque absorbed by the braking continuous-current excited generator will be somewhat greater than that absorbed by the induction generator at all points up to the rotor current corresponding to maximum torque, when the two torques are equal.

If, therefore, arrangements are made so that the opening of the main circuit breaker (owing to failure of supply) automatically closes the stator circuit on to a suitable source of continuous current, and the ammeter, which acts under normal circumstances as a torque indicator to the driver, is placed in the rotor circuit, the driver has, under emergency circumstances, exactly the same reliable guide as he uses under normal circumstances for employing as a brake when working on the limiting torque principle before described. He can use for braking a torque equal to the normal full-load torque of the motor down to a speed which is the same fraction of synchronous speed as the normal slip—that is to say, down to a speed that is perhaps 5 per cent. of the synchronous speed. It is obvious that this speed is so low that any sort of mechanical brake can then safely be applied in order to complete the process of bringing a descending load to rest.

This continuous-current excitation can also be applied to the induction motor of the converter set of a Ward-Leonard system, and would certainly, as an emergency arrangement, increase its safety when lowering loads. Its application to this case is not, however, so simple as its use on the direct-driving induction motor, for it would be necessary for the driver, under the emergency conditions, to pay attention to the reading of an ammeter on which he did not have to depend for normal running.

In this brief outline of a scheme for using the induction motor for driving winding engines, the author hopes that he has gone into sufficient detail to show that although his proposals are more expensive in power consumption where much lowering has to be done, they embody arrangements which are superior to those of the Ward-Leonard system as regards simplicity and safety. Inasmuch as the cost for the simple induction motor is lower than that for a Ward-Leonard set, he considers that he can at least claim that where cheap power is obtainable from a large power plant and capital outlay is a consideration, he has made out a case for the induction motor.

Discussion.

Mr. Patchell: I will read the following letter, dated April 17th, which I have received from the author: "You may like to know that more than academic interest now attaches to this subject. I am Mr. Patchell.

Mr. Patchell.

responsible, under Mr. Robeson, lately the Consulting Mechanical Engineer to H. Eckstein & Co., for putting down induction motors for driving winding engines on the mines of the Witwatersrand to the number of about sixty, of outputs (on continuous rating) ranging from 400 H.P. to 1,500 H.P. These are now being put into commission and several are already running. They are all being tested with reverse currents to brake and pull up descending loads, and so far with entirely satisfactory results. I have never worked out the actual saving in capital outlay that has been secured by using induction motors instead of the Ward-Leonard arrangement, but I do not think it can be under £50,000. As you are no doubt aware, we purchase our power at a fairly low rate." I propose asking Mr. Heather if he will give us some figures to put into the paper. Perhaps when he replies to the discussion he may be able to do so. As we are out of the winding district here I thought it would be interesting for those who have not seen a winding engine to see some photographs, so I have brought some of the Ward-Leonard system, showing how such an engine is erected and handled. The flywheel weighs 30 tons, it is 12 ft. in diameter, and 2 ft. 6 in. wide. The normal speed is 500 revs. per minute, and we allow it during winding to vary 15 per cent. There is enough energy in the flywheel to do four complete winds after the power is shut off. We have a battery in the power station to look after the excitation.

Mr. Mountain.

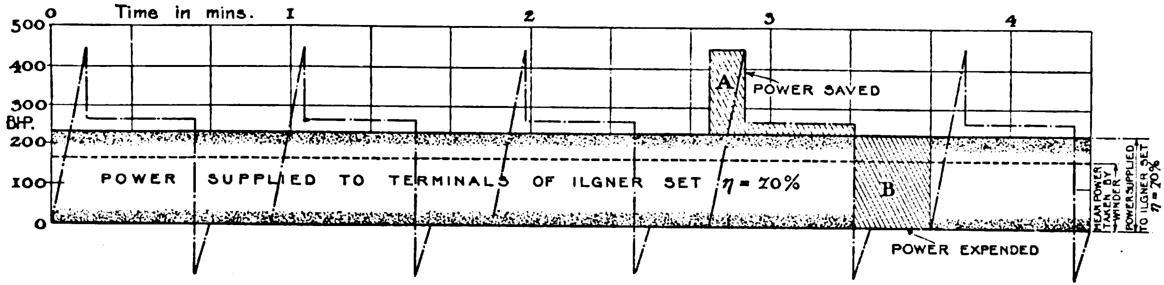
Mr. W. C. Mountain: The economical winding by electricity requires very great consideration, and if the winding can be done by means of an induction motor supplied direct from the mains it necessarily reduces the first cost of the winding gear considerably, and dispenses with the complication of the Ilgner or balancer system. Any subject of this kind, whilst interesting from the academic standpoint, is, however, of very little value unless it can be shown that there are commercial advantages to be derived from it, and, in my opinion, the value of the paper would have been very greatly increased if Mr. Heather had given us some practical examples showing the comparative cost of winding gears of the simple and Ilgner type for the same duty. I have recently carried out a considerable amount of work in connection with winders of moderate capacities with induction motors supplied direct from the mains, and with this type of winder I have invariably adopted a comparatively slow-speed motor driving through machine-cut helical gearing on to the drumshaft with a single reduction, and I believe that this type of gear is one which will find considerable favour in the near future, because it is less expensive than the Ilgner or balancer type of plant and it is also less expensive than supplying the induction motor direct on to the drum shaft, and as the efficiency of machine-cut helical gear is now so very high, there is practically no loss in efficiency between a geared winder and one which is direct driven. There is no doubt that in the North of England, also abroad, and in many parts of this country, there will be a large demand in the near future for

electric winders of moderate capacities, particularly where current can be taken from an electric supply company, and assuming that the supply company will supply the current at a price which will enable electric winding to compete with steam. One of the most important points to consider in any scheme of winding is the source of supply, as this determines to a great extent the class of winder which is to be used, and, in this connection, it may be of interest if I gave an example of an electric winder in the North of England which is fed from the Newcastle-upon-Tyne Electric Supply Company. This winder is fitted with a 3-phase induction motor wound for 5,500 volts at the terminals. The motor is of 700-H.P. normal, but at the moment of acceleration the motor calls for a supply of current equal to nearly 1,700 H.P., and, although the supply is taken from a central station in which eight 6,000-k.w. alternators are installed, and probably four or five at least are at work, every wind is distinctly seen at the power station. Owing to the large capacity of the power station, the volts at the winder remain remarkably constant, but it shows how important it is to consider the capacity of the generating plant from which the supply will be taken when dealing with a problem of this nature. **Mr. Mountain.**

It is difficult in a discussion of this kind to arrive at any definite result without quoting a specific problem, and I therefore give figures in connection with a winding gear of the type referred to, *i.e.*, with induction motor and machine-cut helical gearing, with which I have recently been connected, the particulars being as follows :—

Depth of shaft	780 ft.
Time of winding	40 seconds.
Time of banking	15 seconds.
Average rope speed	19·5 ft. per second.
Weight of coal per wind ...	2 tons 4 cwt.
Circumference of rope ...	4 in.
Nominal horse-power of gear	250 to 500.
Balance rope fitted.	
Period of acceleration ...	8·5 seconds.
Maximum velocity	27·5 seconds.
Retardation	4 seconds.
Acceleration speed	2·73 ft. per sec. per sec.
Maximum velocity	23·2 ft. per second.
Retardation	5·8 ft. per sec. per sec.
Power consumption with induction motor	2·3 units per wind.
Power consumption with Ilgner system, assuming an efficiency of 70 per cent.	2·7 units per wind.

In order to explain the above figures, I have prepared two diagrams,

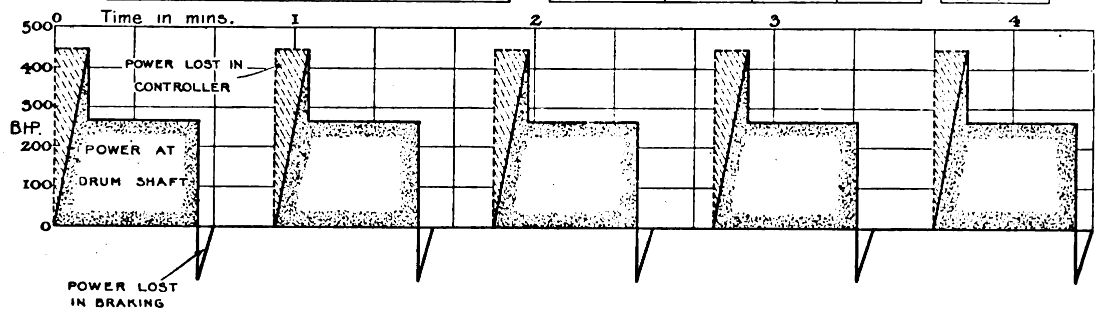


Power Diagram of Winder with "Ilgner" System.

GENERAL PARTICULARS OF WINDER	
DEPTH OF SHAFT 780 FT	2 TONS 4 CWTS. OF COAL PER WIND
TIME OF WINDING 40 SECS.	4" CIRCUMFERENCE ROPE
" " BANKING 15 "	HP OF GEAR 250/500
AVERAGE ROPE SPEED 19·5 FT/SEC	BALANCE ROPE FITTED

TIMES, SPACES & SPEEDS			
PERIODS	TIMES	SPACES	SPEEDS
ACCELERATION	8·5 SECS.	98 FEET	2·73 FT/SEC²
MAXIMUM VELOC.	27·5 "	636 "	23·2 FT/SEC
RETARDATION	4·0 "	46 "	5·8 FT/SEC²

POWER CONSUMPTION	
WITHOUT ILGNER SET	2·3 UNITS PER WIND
WITH ILGNER SET. η = 70%	2·7 UNITS PER WIND



Power Diagram of Winder with Controller.

Mr. Mountain.

one representing the winding with induction motor supplied direct from the mains, and the other with the Ilgner system. It will be observed that each diagram shows that the horse-power required to accelerate is about 440, and, of course, taking the current from the supply company it means that a demand equivalent to 440 H.P. would be required for each wind, but, as the current is switched off the motor before the end of the wind and no current is consumed between the time of cutting off the supply until the next wind, it will be seen that although the momentary demand during the period of acceleration is considerable, the total consumption, allowing for rheostatic losses, is less than with the Ilgner system. Referring to the second diagram illustrating the Ilgner system, it will be observed that the power taken from the mains is equivalent to about 215 H.P., or about half what is required at the moment of acceleration by the induction motor set. This, of course, is assuming that the load upon the motor driving the motor-generator is practically constant. This is not quite so in practice, but it does not affect the final result to any extent. A comparison of the two results shows that whilst the call upon the supply mains is momentarily—*i.e.*, during the period of acceleration—twice what is required by the balancer set, the actual consumption of current with the induction motor directly supplied set is slightly less than with the Ilgner system. It is also necessary to consider the total first cost of the winding gear, and I estimate that the approximate cost is as follows :—

	£
For a winding gear fitted with 3-phase induction motor driving through machine-cut helical gearing, complete with drum, and suitable for the capacity mentioned in my illustration, the cost would be approximately	1,600
For an Ilgner set complete with motor, heavy flywheel, generator, also switchgear and winder for the same duty, price approximately	2,400

A comparison of running costs would be approximately as under :—

Induction Motor Set.

	£
Cost of winder	1,600
Allow for interest and depreciation, 15 per cent. per annum	240
Current consumption, 65 winds per hour at 2·3 units per wind for 16 hours per day, 300 days per annum = 72,000 units at ½d.	1,500

	£
Total cost of winding, omitting oil, stores, and labour, which would be the same in each case	1,740

Mr. Mountain.

Ilgner Set.	£	
Cost of winder	2,400	
Allow for interest and depreciation 15 per cent. per annum	360	
Current consumption, 65 winds per hour at 2·7 units per wind for 16 hours per day, 300 days per annum = 845,000 units at ½d.	1,760	
Total cost of winding, omitting oil, stores, and labour, which would be the same in each case ...		2,120

A further point which has to be taken into consideration in deciding upon plant of this description is the cost of upkeep and risk of breakdown, and it must be remembered that the winding gear is probably the most important piece of machinery at the pit, and requires to be the most reliable.

With the Ilgner type of winder there are a good many links in the chain between the supply and the actual winding drum, consisting of a motor on the balancer, a heavy flywheel running in bearings, a generator driven from the motor, the necessary switchgear, and, in addition, the motor on the winding gear, and all these are liable to go wrong; as a matter of fact, I know of an actual instance in which, owing to the failure of the motor on the balancer, a large colliery was laid off for nearly six weeks whilst the necessary repairs were executed, and, in order to avoid a recurrence, the owners decided to put down a second balancer at considerable expense. With the simple induction motor these complications are to a great extent avoided, but I should be disposed to go even further than common practice and so to construct the induction motors that the voltage for which they were built would enable the simplest possible form of winding to be used on the stators, consisting of plain copper bars in mica tubes. This would, of course, involve transformers where the supply current was of high voltage, but I feel confident that whilst the total cost might be very slightly increased it would be a wise precaution, as any repairs which might be necessary to a high-voltage motor on a winding gear would necessarily take some time to execute and involve the mine owner in very considerable losses, and probable risk of life. This, of course, is a practical objection, and may not appeal to some electrical engineers, but I am sure it is a point which deserves great consideration where reliability is the chief point to aim at.

Mr. Stjernberg.

Mr. G. Stjernberg: The author has apparently had in mind winding propositions as they occur on the Rand. With this limitation it is possible to agree to what is said on page 609 that the efficiency of geared winders driven by 3-phase induction motors can compare favourably with the Ward-Leonard winder. But we cannot transfer this statement to conditions as we know them here. The best possible efficiency obtainable with any system, including steam, will depend on the rapidity of the wind, not as measured by the

Mr. Stjernberg.

average speed or by the maximum speed, but as measured by the ratio between the average speed and the time allowed for the wind. In mining districts this ratio of average speed to total time varies considerably. In England, expressed in metric units, it reaches about 0·3. In Westphalia it rarely exceeds 0·25; in South Africa it rarely extends to 0·15; it is oftener 0·06, which is quite usual, and 0·1 is probably a fair average for these winders on the Rand. The lower the ratio of average speed to total time the more easy it is to suggest a power diagram with a small peak load, and with very small resistance losses, if resistance control is used. It is easier to arrange the running-out so that no braking occurs. The motor losses may be reduced to a minimum. And this applies to both systems. But the difference is in the value of the maximum limit which can be attained. For the Ward-Leonard system I should like to put it at about 0·73. For the resistance control it might reach 0·88. But again, as the ratio of average speed to total time increases, the efficiency falls off, though at a different rate; for the Ward-Leonard, slowly; for the resistance control it drops off quickly. For the Ward-Leonard system the lower limit is about 0·55, excluding shaft friction and mechanical losses. If we persist in carrying out winders driven by induction motors with resistance control up to the corresponding point, the efficiency will sink to 0·35. These figures refer to winding with balance rope. On the Rand they are in many cases not using a balance rope, and if there is no balance rope and cylindrical drums, the limits within which induction motor drives will be efficient will be narrower still. For depths worked in this country we could not as a rule consider winding with induction motors without balance rope. But they have reduced the rope weight to the smallest possible—at least, considerably smaller than here. The factor of safety is about 7, but in this country 9 to 12. Further, they are winding ore which has a higher specific gravity, and this makes the rope weight, as compared with the weight of the load, rather small. In other words, the conditions on the Rand are exceptionally favourable to the use of induction motors with resistance control, and I think Mr. Heather is to be congratulated on having arrived at the decision he has in adopting this type of gear. With regard to the question of simplicity, there is one point that I think deserved a few more words in the paper, and that is the question of the switching connections to be worked regularly during each wind. With the Ward-Leonard system there are no such connections at all in the main circuit, but only in the field circuit which is dealing with a very small energy. To fulfil all requirements, it must be designed in such a manner that there is no electrical wear and tear at all; it is practically a mechanical piece of apparatus. Therefore, once the Ward-Leonard system is well in order, and good work has been put in everywhere, it may be considered very safe. But the resistance control has a number of switching contacts which have to be regularly operated. There is incessant wear on the various parts; and, considering that

Mr. Stjernberg. they are often working 20 hours in one shift, it may be necessary to stop the winder to adjust and look after these contacts, because if once they begin to wear they go rapidly worse. With regard to the braking, I would prefer to have a mechanical brake so designed that I can adjust the braking effect with any degree of nicety which the work may require. The losses are smaller, since we would then only lose the work supplied by the sinking load. In any case, it would be necessary to carry away the heat produced either in the resistance or on the brake, and the brake can be easily so designed that it will be safe to lower any load down the shaft. Electrical braking with counter current can be looked upon as a safeguard, and could always be used as an additional simultaneous adjustment of the braking effect. With regard to the proposal to use direct current if the supply fails, it has, in principle, one defect, that during the moment of switching over, the winder is without control. I think, therefore, whether it is the Ward-Leonard winder, or whether it is the direct winder, so long as there is no means of electrically braking independent of the main supply, without relying upon any auxiliary machines, the mechanical braking should be principally relied on.

Mr. Stoney. Mr. Gerald Stoney: As I have seen something of a winder in the North of England, which is nominally of 700 H.P., but with peaks up to 1,700, I may be excused if I say a word or two. There is a decided fluctuation on the power station with a total load of 30,000 k.w., due to this 1,700 H.P. coming on and off; and I have never been able to make out whether the peak load has a good or bad power factor. I have not gone into it carefully, and probably those who are more familiar with the matter may be able to say whether the variation of voltage may or may not be due in part to the load coming on with a bad power factor. If several winders were on a station there might be serious fluctuations of voltage—in fact, somewhat the sort of fluctuations which we get on a tramway system where there are only a moderate number of trams working. There is one thing to be noticed, that in the Ilgner system the maximum is only about half the power required in the simple system. Mr. Mountain has shown me his curves, and the Ilgner average is 220 B.H.P., the simple system is a maximum of 440 B.H.P., or just double. Therefore it means that it is necessary to have a generating system able to take double the load. The result, of course, will be that if an electrical plant is being put down for driving such things a larger generating station will be wanted. Against that is the fact, as Mr. Mountain informs me, that the simple system costs about £1,600, while the Ilgner system will cost about £2,400. There is a suggestion which might be considered in some cases, and which will enable a simple system to be used and yet have a more steady load on the generating station; and that is, instead of having two cages only going in the shaft, one up and one down, to have four cages working alternately. On an average the time of retardation and stopping at the top and at the bottom of the shaft are equal to the

time of acceleration and moving at an uniform speed. If, therefore, two loads be superimposed, one load over the other alternately, a fairly uniform load would be got. I do not know whether it is practicable: I only throw it out as a suggestion. Mr. Stoney.

Mr. C. H. GADSBY: I would like to ask Mr. Patchell a question with reference to the winding plant which he showed on one of the photographs. I gathered from the picture that it was a direct-coupled motor, and, as far as I could judge, the winding drum must have been some 12 or 14 ft. in diameter. I have been recently engaged on the design of a somewhat similar scheme, and I found that to have anything in the way of a large winding drum, gave an enormous rope velocity with any ordinary speed, with an induction motor direct coupled with it. I should be glad if Mr. Patchell would say about what is the rope velocity in that instance and the number of revolutions per minute of the induction motor. Mr. Gadsby.

Mr. PATCHELL: When I was asked by the Council to read the paper I did not say I would reply to it, and it is not fair to Mr. Heather for me to attempt a reply, because he might not find himself in accord with what I said, and yet he might not care to say so. I therefore do not propose to put him in that invidious position, but will leave him to reply at leisure in writing, when I hope he will be able to give us the figures which I suggested he might, to justify, in a sense, his academic views. He evidently had the courage of his own convictions if he had so many plants on order at the time he sent us the paper. The question of whether the Ilgner arrangement or an induction motor should be applied depends, I think, primarily, on the source from which the current is to be obtained. If, for instance, we are to get it from our own private station, there are not very many cases in which we should care to put down a power station to supply a big winder on an induction motor. If we put it down with the Ilgner system, the figures I gave for Ferndale and the figures which Mr. Mountain quoted show it is within the range of practical politics to run the Ilgner set off a very ordinary power station. Many years ago, when we started electric trams, the clatter of the engines which had to carry traction loads was excessive; but now we do not care whether an engine is on a traction load or an ordinary load, if we can get enough tramcars. With a large number of winders at work there would be a small peak; but that will not bother us, and the diversity factor of the different pits will be enough to take any anxiety off those responsible for operating the generating plant. In Mr. Heather's case, he is not the operator of the plant; he buys from the huge power scheme which we have heard so much of. I have a letter from a friend in South Africa, who wrote me at the end of last year: "My work here goes on well, and a few months will see it completed. The first Ward-Leonard winder is working well. I expect to derive some instructive experience from the alternating-current machine, this being plant of 3-phase, with peak 3,000 H.P., reversing to considerable negative value in an 80-second wind. The power company, however, view the thing with equanimity, and it is certainly Mr. Patchell.

Mr. Patchell.

their trouble rather than ours." So the electrical engineer at the pit does not care if he has not to pay. The news which we are getting from the Rand as to stage winding will make a great deal of difference to the winding load. From the enormous depths to which they are going, they wind up a stage, and then on again. So they have two separate engines to wind from the bottom to the surface. In such cases the direct coupled, or even the geared induction motor, on account of the size of the engine house which is necessary, presents considerable advantages compared with the larger space taken by the Ilgner set. Mr. Heather mentioned the facility with which the winding men changed from the steam to the electric method. It is the same at home. It does not matter whether it is winder or haulage engine, so far as the man who is handling it goes, the operations are very much the same thing. The preference which men show who have changed over to electric haulage from steam or compressed air is quite common, as it is very much easier work. The balance rope, as Mr. Heather says, has not been much used in South Africa. In England also it has been very little used, and that, I believe, is due to a very great extent to the irregular turning of steam-winding engines. The swing of the rope between the drum and the pit-head is often considerable with a steam winder; but on the electric winder the rope runs like a rod—there is no swing. That shows what goes on in the comparatively short distance between the winding drum and the pit-head sheaves; and when we have that magnified many-fold from the under-side of the cage to the bottom of the shaft the cause of the antipathy which colliery engineers have to the balance rope can well be imagined. In the case of an electric winder that difficulty disappears; the balance rope is no trouble at all. The more electric winding gets popularised, the more the colliery engineer will appreciate the advantage of a balance rope. Some one mentioned the question of switching. I remember some time ago watching switching on an induction motor set, with a liquid resistance switch; the sparking was a perfect firework display, and when that is compared with the practical absence of sparking on the switchgear controlling an Ilgner set it is clear that the difference in the wear and tear must be very marked. Mr. Gadsby asked for some figures as to the diameter of the Ferndale drum. It is 16 ft. on the tread. The maximum speed is 63 ft. per second when winding a useful load of 3 tons from a depth of 516 yards. The rated output in 9 hours is 1,800 tons.

I think those are all the remarks I have to make, except to thank members, on Mr. Heather's behalf, for the discussion, and also to express a hope that other engineers abroad will send us the results of their labours, and feel assured that somebody at home will do his best to take charge of the paper for them. I think more members would send papers if they thought somebody at home would give a hand to get the paper through a meeting.

Mr. Jenkin.

Mr. B. M. JENKIN (*communicated*): One point raised in the discussion was the magnitude of the peak load during starting and acceleration.

It was pointed out by more than one speaker that the maximum demand on the supply when using the Ward-Leonard control system with the Ilgner flywheel was about one-half the demand when using the direct-connected induction motor. From this it was argued that when current was taken from an outside supply company the induction motor could be used, as the peak would have to be dealt with by the supply company and did not therefore matter to the owner of the winding plant; also if the owner had his own generating station it would pay him to use the Ilgner flywheel in order to keep down the peak load, so that he might use smaller generating plant. It may, however, often be the case that the charge for a supply by a Company is based partly on the maximum demand made. In this case it is to the owner's interest to keep down the peak, and he might not therefore be able to use the direct drive. On the other hand, where the owner has his own generating station, it would surely be a much cheaper and simpler method to fit a flywheel to his generator, and to design the generator with good inherent regulation, so that it could take the short peak load with only a comparatively small drop in speed and voltage. It is, to a great extent, the flywheel in the Ilgner system that levels the peak, but it might be much less costly to put this flywheel on the steam generator than on a separate motor-generator, and practically the same result, of keeping down the size of the generating plant, is obtained. Mr. Jenkin.

Messrs. J. C. MACFARLANE and H. BURGE (*communicated*): We might certainly say that Mr. Heather appears to have made the best of a bad case. One of the points in the paper to which we take exception is that Mr. Heather has assumed that the direct induction motor drive for winding engines is necessarily less costly than a converter system, and has also assumed that it is a very easy matter to get rid of the large amount of rheostatic waste energy, which is an unfortunate feature of the system upheld. It is also stated that the number of links in the chain of the induction motor drive is smaller than that of the Ward-Leonard or other converter system; but we cannot agree that this is any advantage, as large rheostats are, in our experience, very cumbersome and particularly liable to get out of order. Apart from the fact that the control with the direct-driven induction motor is not nearly so smooth as that with the Ward-Leonard or other converter system, the plant is liable to rougher treatment by the driver. Further, the space taken up by the induction motor and its control gear is greater, and the problem of ventilation of the engine-room might in many cases cause trouble. No mention has been made of the fact that to get the same rate of acceleration with the induction motor, approximately three times the current would be taken, due to the power required during acceleration being more than twice as great in the induction motor case than in the other, and also due to the fact that this power would be taken from the mains at a low average power factor. We would therefore suggest that the chief reasons why the Ward-Leonard or other converter system is used as against the plain induction motor drive is: first, that the current demand from the mains during the period of Messrs. Macfarlane & Burge.

Messrs. Macfarlane & Burge.

acceleration is approximately only one-third that of the induction motor drive; secondly, that the control is much simpler, and that with special arrangements the rate of acceleration can be fixed and taken out of the hands of the driver; thirdly, the regenerative properties of the converter system; fourthly, the efficiency of a properly designed converter system is better than that of the induction motor system; and, lastly, these advantages are obtained with practically no addition to the cost. Before discussing the question of cost and efficiency we desire to describe a system which we consider has many advantages over the Ward-Leonard or plain induction motor drive. The connections of this system are shown in Fig. A. The 3-phase supply is

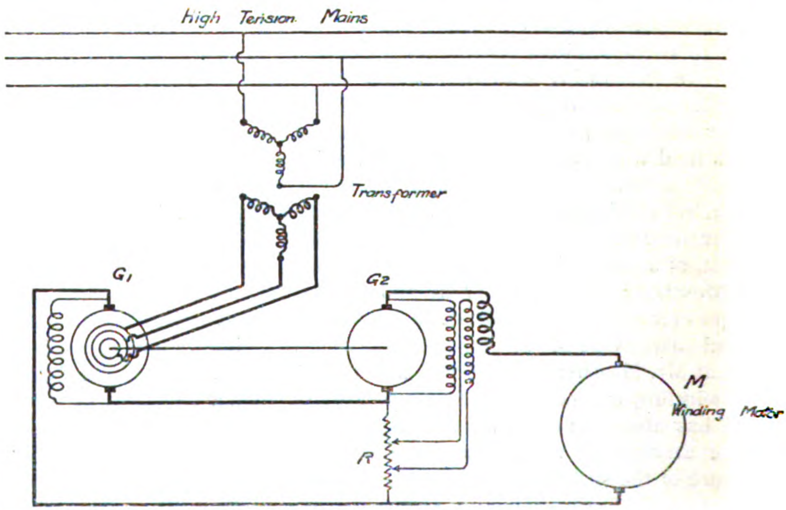


FIG. A.—Diagram of Connections for Special Motor-generator operating a Continuous-current Motor.

converted to direct current at variable voltage by means of a special motor-generator G_1 G_2, and controller R. The direct-current winding motor M is shunt wound with variable field strength, arranged to be about twice as great at starting as when running at full speed. G_1 and G_2 are two similar direct-current machines coupled together. The armature of G_1 is tapped to slip-rings, through which the power is taken from the supply. The excitation of G_2 is supplied from G_1 and is varied between a positive and negative maximum by the reversing field regulator R. It will be seen that these are not very large machines, as each one has only to deal with approximately half the power. The advantages of this system are as follows: By using a motor with variable field strength the torque at starting can be twice the normal without the current to the winding motor much exceeding the normal value, hence the C^2R losses are no more at starting than

at full speed, and to this end the motor-generator is designed to give, with the controller full on, a nearly constant current characteristic as indicated in Fig. B. At starting, the controller is thrown right over

Messrs. Macfarlane & Burge.

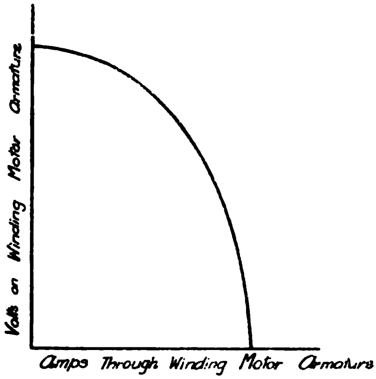


FIG. B.—Continuous-current Characteristic of Motor-generator.

to "full speed," and the maximum permissible acceleration is then obtained. The winding motor being shunt wound will, in the event of the load running away, regenerate on the supply mains and act as

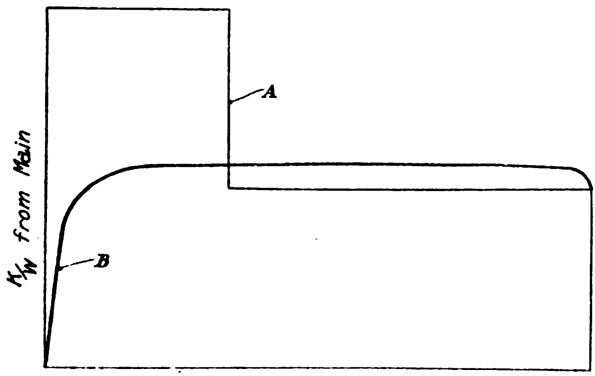


FIG. C.—Curve of Kilowatts demand from Mains.

A. Direct induction motor drive.
B. Motor-generator drive.

a brake, the regenerated current being also limited to a safe value. The great advantage of the above system from the point of view of the power supplier is shown in Fig. C, where curve A represents the power absorbed during a wind with a direct induction motor drive, the large demand during acceleration being due to the power wasted

Messrs. Macfarlane & Burge.

in the starting resistances. Curve B represents the new system, in which it is seen that the power demand is nearly constant, and it should be noted that the power factor is practically unity throughout. It is possible with the adoption of the new system to raise a ton of coal 1,000 ft. for under 1d., taking power at ¾d. per unit; whereas in most cases it would be impossible to obtain power as cheaply with the induction motor drive, due to the large maximum demand. With regard to the first cost, the table below shows the relative cost of the three systems, namely, the direct induction motor drive, the plain Ward-Leonard drive, and the converter system described above.

	Induction Motor Drive.	Ward-Leonard.	Converter System described Above.
	£	£	£
Driving motor	400	300	300
Control gear	300	50	50
Motor-generator or converter		500	300
	700	850	650

In the above, the average winding power is assumed at 300 H.P., a fairly common figure in this country, and the size of the induction motor is estimated on the assumption that it is capable of giving out 600 H.P. about 100 times an hour for 7 or 8 seconds at a time. The control gear price includes a liquid controller of 300-H.P. capacity. The direct-current motor in each case is the same for the Ward-Leonard and converter system described, and the converter, which in one case consists of an induction motor-generator, and in the other case consists of the converter described above. The prices set out for these are on the same basis as the prices for the induction motor, assuming that the load, however, never rises above 300 H.P. No allowance has been made for the larger cables required to carry the very heavy currents from the rotor to the control gear in the case of the direct induction motor system, nor has anything been allowed for the extra room and the necessary ventilation that would be required to put this system on the same basis as the other two. The table shows conclusively that the Ward-Leonard system does not cost 20 per cent. more than the direct induction motor, and the system described above costs rather less. Mr. Heather states on page 622 "that the dissipation of the large amount of energy in the case of a large winder need not present difficulty in practice to the mechanical engineer," but we think that as compared with the simplicity of the Ward-Leonard system it is extremely difficult, and the author does not mention what it is going to cost. It would also be interesting to have the author's comments on the question of the upkeep of this control gear. On page 625 Mr.

Heather states that the induction motor used with the Ward-Leonard equipments is usually made large to prevent it falling out of step, but this does not either apply to the system outlined above or even to the ordinary Ward-Leonard system, as the Ward-Leonard arrangement has the large advantage of a storage of power in the inertia of the machine itself, and it is never necessary with the Ward-Leonard system to make such large demands as in the case of the ordinary motor. If, however, the supply is limited by the method outlined above, which can be and has been applied to the Ward-Leonard system, then it is impossible to create a demand larger than a pre-determined figure. Mr. Heather also states that the control of the induction motor can be made equally as simple as the Ward-Leonard control by the use of a double ammeter, etc., but surely, as the first cost of the two systems is almost the same, and there are so many advantages in favour of the Ward-Leonard and other systems, the introduction of these complications is not worth while. Messrs. Macfarlane & Burge.

Mr. R. LIVINGSTONE (*communicated*): Mr Heather puts the case of the induction motor drive of winding gear very clearly, and with regard to efficiency and ease of operation I am entirely in agreement with him in the statement that they compare favourably with regenerative systems having the Ward-Leonard control. The efficiency of the mechanical portion of the winding gear varies from 60 to 80 per cent., depending on the depth of the shaft and the number of tons per wind. The over-all efficiency of the electrical gear between the winding drum and the power mains varies from 55 to 70 per cent. when a motor-generator flywheel set is used, so that the resulting over-all efficiency is only 33 to 56 per cent. With good acceleration and moderately long winds this efficiency can be obtained with the simple induction motor drive, in spite of the large rheostat losses during the acceleration and retardation periods, and the speed control is, as explained by the author, quite as simple as in the Ward-Leonard or other methods of control. With an induction motor drive, however, gearing between the motor and the winding drum is essential if a motor having a good power factor and efficiency is used. It is well known that good power factor and efficiency can more easily be obtained with high-speed induction motors than with slow-speed ones, and since winding speeds of much over 3,000 ft. per minute are not considered practicable, it follows that the winding drum cannot be run at more than 120 revs. per minute for short winds of small power and cannot be run at more than 65 revs. per minute for long winds of large power. An induction motor speed of 375 revs. per minute is consistent with good economy up to very large sizes (2,000 H.P.), but the necessary gearing may be a source of trouble. To deal with the enormous powers encountered in winding sets, gears having very high peripheral speeds (2,000 to 3,000 ft. per minute) must be used, and it would be of interest if the author could give some account of the size and running of the gearing in the plants which he has tested. A common source of trouble in induction motor drives of Mr. Livingstone.

Mr. Livingstone. winding drums or rolling mills is the slip regulator. Not only must this part of the equipment be able to dissipate a large amount of energy, but it is subjected to rough treatment in the ordinary operations of winding. When we remember that the motors must be started from rest and brought to full speed in 10 to 20 seconds it is evident that the regulators must be operated very rapidly, and the most feasible scheme seems to be to move the liquid in the resistance by means of powerful pumps instead of moving the plates of the apparatus by motors.

High rates of acceleration are necessary if induction motors are to be economically used, but such motors are more expensive than smaller powered motors which give a less rate of acceleration. There is, of course, a point where the increased capital cost of the motor and gearing begins to outweigh the saving in current by increasing the acceleration, and there is also a practical limit to the rate of acceleration of about 8 ft. per second per second. Each case must be worked out on its merits, but I am inclined to think that the "best" rate of acceleration will not vary considerably, and I should think it would be about 3 to 5 ft. per second per second with current at ½d. to 1d. per unit. The author's opinion on this point would be of value. The connection of such large units as are necessary for winding plants direct to a power company's mains cannot be done in many districts, and in such cases a flywheel equaliser is necessary. This, of course, is a serious limit to the direct drive by induction motors, since, if a flywheel set is necessary, an economical Thury or Ward-Leonard system of control might as well be used in conjunction with direct-current generators. The large amount of power wasted during retardation periods by the induction motor drive would be serious when much single-drum working is used, or when the winding of men at slower speeds and smaller accelerations than the normal is a considerable item in the day's work. In such cases a direct-current flywheel equipment is again the most economical. The author rigidly adheres to braking by means of the rotor of the induction motor, but it is a question whether it would not be possible to design a mechanical brake with a suitable cooling device which could satisfactorily absorb the energy lost in retardation. Such a device need not complicate the method of control to any serious extent, and the problems involved by the dissipation of the large amount of energy lost in the brakes can be solved by designing suitable brake-gear. It would only be commercial, however, when the capitalised value of the current saved exceeded the cost of the brake-gear. The eddy-current brake described in a recent paper before the Institution* is one example of a method of braking which seems to possess good features, though I had in mind a design in which the brake rings were water-cooled, of very ample dimensions, and with the brake blocks operated by compressed air or water under pressure.

* *Journal of the Institution of Electrical Engineers*, vol. 35, p. 445, 1905.

Mr. Heather.

Mr. H. J. S. HEATHER (*in reply*): Before dealing with specific points raised in the discussion on this paper, I think it will be of interest if a few remarks are made on some of the circumstances that contributed to its being written. About eighteen months ago I got out a specification for the conversion to electric driving of four steam-driven Whiting hoists. The work to be done by each winder necessitated a peak load of about 2,500 H.P. and a continuous load rating of about 1,500 H.P. It was specified that the motors were to be induction motors built on the sheave shafts. At the last moment two firms of world-wide repute, who were invited to quote prices, withdrew their tenders on induction motor drives and combined to substitute a joint tender on Ward-Leonard equipments. As I was quite certain of what I wanted and equally certain of the satisfactory feasibility of my proposals, the order was placed with a third manufacturer, and an intimation was sent to the firms who declined to tender on induction motors that I anticipated that their attitude would become of historical interest. It is noteworthy that, as far as I am aware, no representative of either of the firms referred to has come forward during the present discussion to attempt to justify the position taken up by them eighteen months ago, and to combat my assertion that winding with induction motors is safer than with the Ward-Leonard control without flywheels. It may now be stated that although, for reasons entirely unconnected with electrical matters, the winders mentioned are not yet put into operation, another one of practically equal size and under similar conditions, driven by an induction motor, is at regular work on these fields and is giving entire satisfaction. This last winder is at No. 2 shaft of the Brakpan Mines. With these preliminary remarks I will now proceed to deal with the points raised in the discussion.

In the first place, there has been a somewhat general request for figures on the cost of winding by induction motors. Actual figures are not yet available on the large scale, as the new winders are only now being got to work. Unquestionably, however, in the course of a few months a very large amount of information will be obtained. No general conclusion applicable to all cases as to comparative costs of winding with induction motors and the Ward-Leonard system can ever by any possibility be reached. Each case must be considered by itself, and a general discussion is therefore entirely unprofitable. Even under the circumstances with which I had to deal—viz., with power purchased at a flat rate, and a general absence of tail ropes—it would have been quite impossible to apply results obtained from any one shaft to any other. Differences would have arisen in connection with shaft depths and inclinations, permissible speeds, comparative amounts of lowering loads, and so on. The periods over which amortisation would have to be spread would also have to be taken into account. The shaft depths being usually great in comparison with English conditions, there will undoubtedly be a fairly considerable saving in working costs by using induction motors on the mines of the Rand Mines and Eckstein groups. In the matter of capital outlay, a general conclusion can be

Mr. Heather.

reached: it is that the induction motor is the cheaper system. This was of considerable importance in the case I had to undertake, where capital expenditure had to be kept down. The particular question that my paper dealt with was the application of induction motors from the points of view of simplicity and safety. My endeavour to prove that the electrical control of the induction motor was practically perfect has apparently been misconstrued by Mr. Livingstone, who thinks that I propose to abandon mechanical brakes in practice. This, of course, was not my intention. In stating that it was possible to perform all the operations required in winding by electrical means with an induction motor, I was merely trying to demonstrate in words what I have often done with the actual electrical machinery. I have always, however, had mechanical brakes to fall back upon, and, very properly, should not be allowed by the Mining Regulations to abandon them. Still, without the mechanical brakes it is just as easy with the induction motor as with the continuous-current motor to balance any load in any position, and to start it in either direction from rest, or to stop it electrically when in motion.

Mr. Patchell has mentioned the fact of trouble having been experienced with flashing at the blades of a liquid controller. This very often arises from using a liquid of too high a conductivity, and may also be due to the shape of the blades. I have usually found it necessary to modify in some way or other those sent out by the makers.

It will interest Mr. Stoney to learn that his suggestion for dealing with the peak—namely, arranging periods of hoisting on two winders so that the acceleration period on one corresponds to the retardation and stopping period on the other—was actually put into practice some years back on the Robinson Deep Mine here. The winders were driven by induction motors which were supplied at that time by a comparatively small generator on the mine. The arrangement satisfactorily achieved the purpose for which it was put in.

With most of Mr. Stjernberg's remarks I am in complete agreement. He has, however, not given quite a wide enough range to his figures for the ratio of average speed to total time of wind on the Rand Mines; we have cases where this is somewhat higher than the 0·15 he mentions as a limit. On the Village Main, for instance, it is 0·19. In the time allowed for winding I include the time of tipping in getting this figure. I agree with him that the part requiring most attention on induction motor winders is the reversing contacts. On a winding load, however, a frequent periodic inspection is very easily arranged for.

In Messrs. Macfarlane and Burge's communication I find that there is very little with which I can agree. It is, I think, hardly fair to say that I have "assumed" that induction motor drives cost less than converter arrangements. I have asked for tenders on both systems, and without exception have found the induction motor to be cheaper, and this in spite of the fact that my knowledge of costs of manufacture enables me to say that the proposed profit on a Ward-Leonard equipment has been in some cases cut down to the vanishing-point in order

Mr. Heather.

to get them put in. Neither have I "assumed" that it is an easy matter to get rid of waste rheostatic energy. I have got rid of it and found it to be an easy matter. I am afraid Messrs. Macfarlane and Burge have been unfortunate in their experience of large rheostats. The ones I use are not "particularly liable to get out of order." The worst inconvenience I have had has been due to having to use on underground winders acid mine water for cooling purposes. As regards smoothness of control, the induction motor is absolutely equal to the Ward-Leonard. There is no reason why it should not be, for in a liquid controller the steps are naturally infinitesimally small, whilst in the metallic control of the field magnets of a Ward-Leonard system the steps must be of finite size. It is the self-induction of the magnet windings of the Ward-Leonard system that minimises the effect of an essentially jerky control. I do not see why Messrs Macfarlane and Burge should say that an induction motor is liable to get rougher treatment from the driver than a continuous-current one. I have never noticed this peculiarity, but it can fairly be said that rough treatment of an induction motor is less likely to cause serious damage than in the case of a continuous-current one. It is, for instance, possible to break a rope with a continuous-current motor with a good flywheel behind its generator, but it is not possible to do so with an induction motor, for the latter will "pull out" at a torque that cannot be exceeded except by the application of an increased voltage. I do not think I need deal with further details of Messrs. Macfarlane and Burge's letter, beyond pointing out that in one place they say the advantage of a converter system can be got at "practically no addition to the cost." They then proceed to give a table (with the figures of which I do not agree) in which they state the costs to be £700 for the induction motor and £850 for the Ward-Leonard, and they go on to say that this "table shows conclusively that the Ward-Leonard system does not cost 20 per cent. more than the direct induction motor." The figures on the double generator system I ignore, as the writers have left out a transformer which would be necessary to reduce the voltage at which transmission to winding engines is economically practicable to that suitable for a converter of the type they propose.

Mr. Livingstone has asked for the rate of acceleration on which I figured, and suggests that with current at from ½d. to 1d. per unit the best rate is from 3 to 5 ft. per second per second. The price we pay for current is slightly over ½d., and I reckoned out the larger of our hoists at 3·5 ft. per second per second.

There is one point that has been raised twice in the present discussion, and that I am very glad to have the opportunity of dealing with in a more or less public manner, as I have had to devote a considerable amount of time on various occasions in discussing it with individuals. I am alluding to the very prevalent but erroneous idea that a slip-ring induction motor when taking a large current during acceleration has a very low power factor. This is not the case. The

Mr. Heather.

power factor at any given amperage is to all intents and purposes the same whatever the speed may be. When I say to all intent and purposes I mean within 1 or 2 per cent. Whatever differences exist are due to the friction and rotor iron losses being different at the low speeds from what they are at full speed. Both these losses are small and the changes in their effects caused by differences in speeds are in opposite directions. A winding motor is accelerated at some current between that corresponding to normal load and that corresponding to maximum torque. At the latter current the power factor must always be very close to 0·7. During acceleration, therefore, a winding motor must always have a power factor lying between that at normal load and 0·7, that is say a fairly high power factor. The truth of this can easily be seen by constructing a Heyland diagram, though perhaps the most convincing way is to watch an ammeter and a wattmeter during the process of starting a trip.

In conclusion, I wish to express my sincere thanks to Mr. Patchell for the trouble he has been at in presenting my paper. It is no small encouragement to oversea members to get sympathetic treatment for their contributions.

On the motion of the Chairman, a resolution of thanks to the author for his paper was carried by acclamation.

Proceedings of the Five Hundred and Twenty-Fourth Ordinary General Meeting of the Institution of Electrical Engineers, held on May 18, 1911—Mr. S. Z. DE FERRANTI, President, in the chair.

The minutes of the Ordinary General Meeting held on May 11, 1911, were taken as read, and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Hall.

The following list of transfers was announced as having been approved by the Council :—

TRANSFERS.

From the class of Associate Members to that of Members :—

Walter Evans Chappell.
Arthur Percy M. Fleming.
Charles Wheusa Nicholl.
Clifford C. Paterson.
Percy John Pybus.
George Andrew P. Weymouth.

From the class of Associates to that of Members :—

Frederick William Sedgwick.

From the class of Associates to that of Associate Members :—

Harry Francis Deane.

From the class of Students to that of Associate Members :—

Robert Crawford.
Charles Norman Maclean Hamilton.
Harold William Pink.
John J. Richardson.
Leslie D. Wainwright.
Julius Montague Webster.
Felipe Zapata.

From the class of Students to that of Associates :—

Norman Benjamin Deane.
Frederick Ernest Squire.

Donations to the *Library* were announced as having been received since the last meeting from The Board of Education, The British

Westinghouse Electric and Manufacturing Company, Ltd., The Bureau of Standards, Washington, The Electrical Press, Ltd., The Engineering Standards Committee, G. Mogg, A. G. Pratt, S. Rentell, and C. Weiss; to the *Museum* from the National Telephone Company and H. F. D. Jacob, to whom the thanks of the meeting were duly accorded.

The following paper, "Automatic Telephone Exchange Systems," by Mr. W. Aitken (page 651), were read and discussed.

AUTOMATIC TELEPHONE EXCHANGE SYSTEMS.

By W. AITKEN, Member.

(*Paper received April* 4, 1911. *Read before* THE INSTITUTION, *May* 18, 1911.)

In this country the development in the past has been almost entirely with manually operated switchboards. This type of switchboard has progressed from magneto drop indicator and call wire working, through various stages with mechanically and electrically restored indicators and branching jacks instead of series jacks, to the full common battery switchboard with parallel wiring and relays controlling lamp signals.

From time to time automatic features have been introduced to simplify the operating, and thereby expedite the speed of connection. These automatic features have been principally introduced on the incoming junction switchboards which control the work between different exchanges in the same area, and where it is essential that the operating be of the very best. The insertion of the connecting plug into the jack of the line wanted, in addition to making the connection between the two lines, automatically cuts off the operator's testing circuit, introduces the supervisory signals, and in many cases connects up the ringing circuits so that the subscriber is automatically intermittently rung until he answers. Fig. 1 shows how this is attained, and the model alongside will show it in actual working.

Keyless ringing incoming junction circuits have been designed both to expedite operating and facilitate maintenance. They allow of the number of incoming junction lines per operator being increased from 27 to 36, with actually less fatigue to the operator, and, by substituting a double make and break relay for the electromagnetic ringing key, the wiring of the circuits is greatly simplified and the cost per circuit reduced.

As in the ordinary key-ringing incoming junction circuits these circuits may be arranged for either order wire or call by ringing working.

In the case of keyless circuits worked by call wire, the connections incoming at a common battery exchange, from another common battery exchange are shown in diagram Fig. 1. These are worked as follows:—

The A, or originating operator, presses an outgoing call-wire key

which connects her telephone set with that of an incoming junction, or B operator, at the exchange of the subscriber wanted, and distinctly articulates the number of the subscriber wanted. The B operator selects and advises the number of a disengaged line, and taps the tip of the associated plug P on the bush B of the multiple jack of the line asked for. If this line is free the plug is inserted and a circuit is completed which operates the 83½ ohms third conductor relay R^1. This relay automatically disconnects the operator's testing circuit T from the tip of the plug P, and puts the latter through to the tongue of the relay R^2. The A operator inserts her calling plug P^1 into the outgoing jack J of the junction allotted. A circuit is then completed from earth at the A position, through the winding of the supervisory relay R^7, over the A wire of the junction line, through the 12,000-ohm winding of the clearing relay R^6 and back to battery by the B wire and winding of the retardation coil C^1. This operates relay R^6 without energising the supervisory relay R^7 and lamp L^1. Another circuit is completed from earth through the called subscriber's cut-off relay R^8 and the third conductor relay R^1, lamp L^2 to battery and earth, and in parallel with L^2, the contact of the 12,000-ohm relay R^6, and the third conductor relay R^1 to the armature of the tripping relay R^4, thence *viâ* the contacts of the latter and the ringing disconnecting relay R^3 (a short circuit across the coil of the relay R^3), to the relay R^2, battery and earth. This shunts out the clearing lamp. The relay R^2 then operates and completes a circuit from an earthed ringing generator through the tripping relay R^4 winding, to the tip of the plug, over the line and back to the ring of the plug, 40-ohm spool, battery and earth. The ringing current is connected to the tripping relays at regular intervals, and an earth connection is applied between the periods of ringing, by means of commutators on the ringing machines. The subscriber's bell is thus rung intermittently. When the receiver is lifted to answer, a circuit is completed through the microphone, from earth, through the tripping relay winding R^4, through the A wire and back by the B wire and 40-ohm spool to battery and earth, thereby operating the tripping relay R^4 which is insensitive to an alternating current. R^4 opens the short circuit across the coil of the relay R^3, which immediately operates and short circuits the relay R^2, which, being then de-energised, connects the A and B wires through to the repeater. The supervisory relay R^5 is then operated, the circuit being from positive of battery, winding R^5, the A wire, the microphone, the B wire, and the 50-ohm retard coil C^2 to negative of battery, and R^5 shunts the 12,000-ohm winding of the clearing relay R^6 by its 27-ohm coil, thus allowing sufficient current to flow through the supervisory relay R^7 to energise it and darken the calling supervisory lamp L^1. Once operated, the relay R^3 remains energised. When the subscriber replaces the receiver, the armature of the supervisory relay R^5 falls back and removes the 27-ohm shunt from the clearing relay R^6, and the high-resistance coil allows insufficient current to flow to keep the distant supervisory relay R^7 operated. The

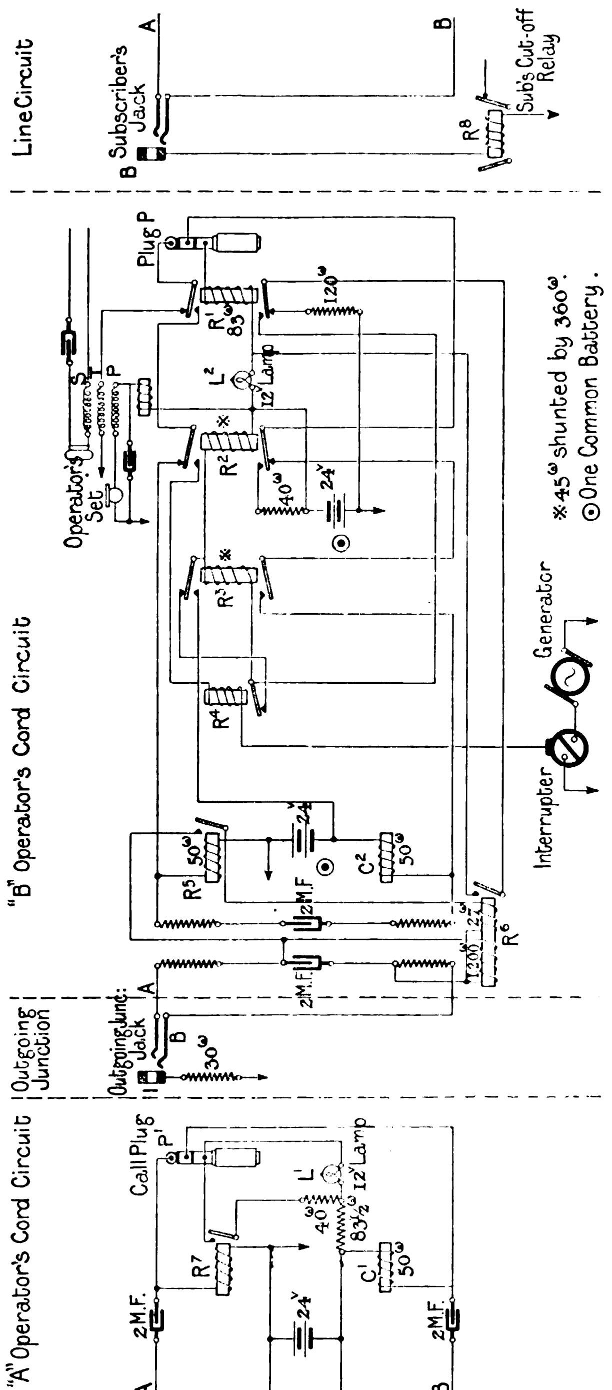


FIG. 1.—Common Battery Incoming Junction Circuit from Common Battery Exchange, Keyless Ringing, Calling by Order Wire.

lamp L^1 therefore glows and the A operator clears, de-energising the clearing relay R^6, thereby opening the circuit of the relay R^3 and breaking the shunt circuit about the clearing lamp L^3 which now glows. The operator clears and the line becomes normal. A 120-ohm spool is placed on the back contact of the third conductor relay R^1, so that if an A operator engages a junction line before the incoming plug is inserted the lamp is glowed, the incoming operator thus being automatically advised should the A operator plug into the wrong jack or should the incoming operator pick up the wrong plug.

It will be seen that the whole of the foregoing is quite automatic with the exception of the insertion and the withdrawal of the plugs.

The British Insulated and Helsby Cables, Ltd., have lately introduced small switchboards of my design, in which the connections are controlled by a rotary multi-contact electromagnetic switch, so that when a connection is made manually, it is held electrically and automatically disconnected, and all apparatus restored to the normal condition when the subscriber replaces the telephone receiver after a conversation. The working model demonstrates fully the efficiency of working. At present, on small switchboards, clearing signals are given to the attendant when the telephone is replaced; but with these new switchboards the lines are automatically disconnected, and all apparatus restored to the normal condition by the replacing of the telephone. This will make the work from the private branch exchange to the central exchange much more positive, and prevent delays occurring at the central exchange due to slow operating at the private branch exchange. These boards are, primarily, designed for small exchanges where there is no regular attendant, say, up to twenty or thirty lines.

With the present class of boards it will be at once realised that slow operating will prejudicially affect the operating in the central exchange. For example, if a connection has been made, at the private branch exchange board, between the exchange line and an extension line, and the telephone at the extension instrument is now replaced after a conversation, the clearing signal will show immediately at the central exchange and at the private branch exchange. As there is no regular operator, however, at the latter, the line having been cleared at the central, another operator may connect and fail to get the private branch exchange switchboard, but would call the extension instrument, and so a delay in operating would be caused. Again, if the extension line, after clearing to the central exchange, desire a second connection to another line on the private branch exchange board, a false call will be sent in to the central exchange, again interfering with the efficiency of the operating there. Such troubles cannot arise with a board giving automatic disconnection, as a second call in either direction would cause the line indicator to respond.

The multiple contact electromagnetic switch consists of a rotary selector arm which has an iron disc attached and is fitted over an electromagnet. The electromagnet sheath has the necessary groups

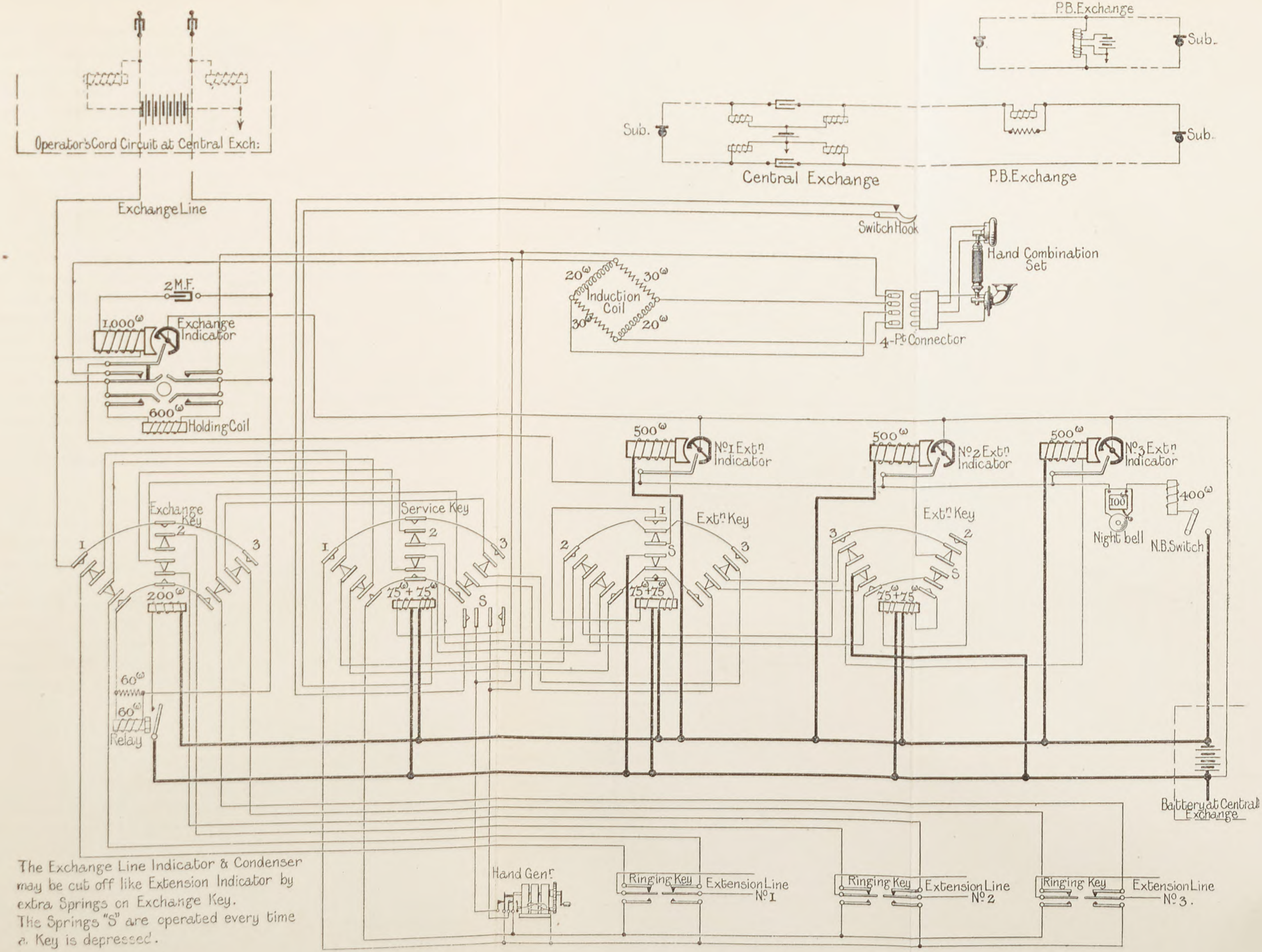


FIG. 2.—Common Battery Automatic Disconnecting Cordless Board for One Exchange Line and Three Extension Lines.

of springs attached to connect with the number of extension lines required. Each group of springs is so arranged that when the rotary selector arm is depressed and the magnetic circuit closed, one set of springs breaks from inner ones, which disconnect the line indicator and battery of the extension line, and connect the extension line through to the exchange. The exchange speaking and holding key is linked up to the rotary switch in such a way that when the connection is completed by the rotary switch the holding key is automatically returned to the normal position.

Fig. 2 shows a diagram of connections for a board having one exchange and three extension lines, and Fig. 3 the circuit for larger boards.

On the former a complete multiple is provided, *i.e.*, the exchange line and the service switches have groups of springs associated with all the lines; No. 1 switch has groups for all lines above No. 1; No. 2 switch has a group associated with No. 3 switch. A connection between two lines is completed by the depression of one switch.

In larger boards connector circuits are used, and these are the equivalent of cord circuits on ordinary boards. A relay is provided per line to cut off the local battery, when a connection is put through to the exchange, the electromagnet of the extension line then being in a local circuit; two plungers are depressed to complete a connection. As many connector circuits are provided as may be deemed necessary.

The operating is as follows: When a call is received from the exchange, the operator pulls over a speaking key and, at the same time, automatically restores the indicator shutter; after learning the requirements of the exchange the key is put to the holding position and the attendant rings the extension line wanted through the service switch, and after receiving a response moves the exchange multiple contact switch to 3 (if that is the number required) and depresses the key, when the current from the central exchange holds the electromagnet energised as long as the telephone is removed at the extension instrument. The winding of the electromagnet may be in series in the exchange line, and of 30 ohms resistance, and shunted by a condenser or non-inductive resistance of 70 ohms, so as not to interfere with the speaking efficiency. Instead of the switch electromagnet being placed directly in the line circuit, it may be replaced by a slow acting relay with the switch electromagnet connected in the local circuit.* The advantage of this arrangement is that the switch-hook at the terminal station may be moved up and down to pulsate the lamp at the central exchange without disconnecting the circuit at the private branch exchange board. A second connection may thus be obtained through the central without the intervention of the private branch exchange operator. Where ringing current is supplied from the central exchange, the operating is improved by fitting a ringing key in connection with each extension line, so that the attendant, on receiving a demand from the exchange for an extension line, presses the ringing key and rings

* This was introduced after a conversation with Mr. F. Gill.

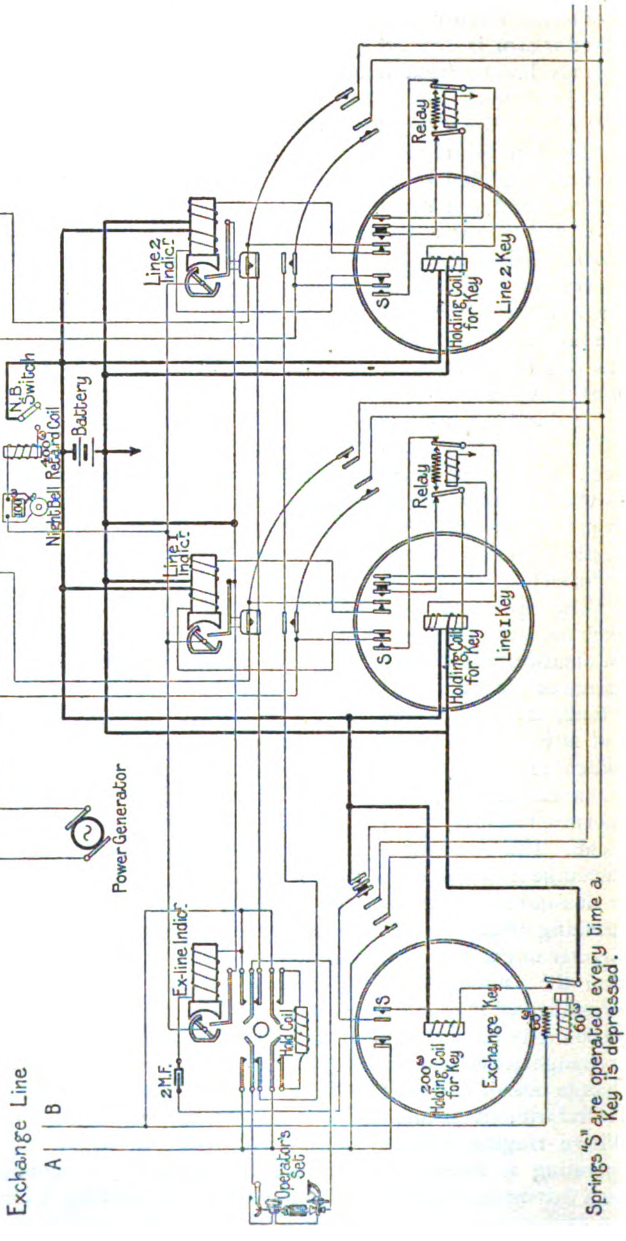


FIG. 3.—Diagram of Common Battery Automatic Disconnecting Cordless Switchboard for Exchange Service, with Connector Circuits and Relays.

on the extension line until the line indicator shows a reply, and then moves the selector switch. This avoids the necessity of placing a holding coil across the exchange line whilst the operator is calling the extension.

When a call is received from an extension line, the attendant calls the exchange by switching into the circuit and then making a connection by the multiple contact switch. After a conversation the replacing of a telephone cuts the battery circuit, and, therefore, the electromagnet is de-energised, and a controlling spring lifts the armature and plunger, and the line is automatically severed and the line indicators thrown into circuit.

The advantages of these facilities will be appreciated by the attendant at the private branch exchange, as it is only necessary to make a connection, when all responsibility for the operating is finished. In most private branch exchange boards the night or alarm bell is used in connection with the line indicators where there is no regular attendant, so that an audible call is received; but, frequently, the night bell is not fitted in connection with the supervisory signals, so that no audible clearing signal is given, and, therefore, connections may be retained completed longer than is necessary, to the detriment of the service at the central exchange.

The first full automatic switchboard used in this country was one patented by Mr. D. Sinclair, when engineer for the National Telephone Company, Glasgow, which was for single-wire circuits only, and was efficient for one junction line and five subscribers' lines. When a subscriber called his indicator made contact with a sliding bar which connected the calling line to the junction line to the central exchange, and insulated all the other lines. A few of these were in use in Scotland for some time.

Little more was done in connection with automatic telephony in this country—unless we take notice of exhibits made by Messrs. L. M. Ericsson of small automatic switchboards, which were in use in Sweden—until Mr. A. M. T. Thomson put forward his semi-automatic system, which was on exhibition for some time at the General Electric Company's premises about 1901.

In this system the number required was built up on the instrument and sent in to the exchange as a series of impulses which actuated an electromagnetic counter device which caused the number to be shown in front of the operator. The operator had no telephone and mechanically, by the usual plugs and cords, connected the subscriber calling with the number revealed. The transfer system of working was adopted so as to save the multiple of the switchboard, and great claims were made for excessively speedy operating, but the system was never put into actual use.

In other countries, particularly in America, automatic systems have been put forward from time to time. In the early days there were the Strowger, Faller, and Callander systems, and later, we find the Lorimer, the American Automatic Company, and others, but the only

system that has obtained commercial success and has been introduced on a large scale is what was formerly known as the Strowger system, greatly improved by Keith, and others, and now known as the Automatic Electric Company's system.

Most of the leading telephone manufacturers are now busy developing automatic systems, but, practically, there is only one system in common everyday use—that of the Automatic Electric Company, of Chicago. It is claimed by this company that there are 300,000 telephones working on their system, San Francisco, Oaklands, Los Angeles, Columbus, Grand Rapids, and Chicago, being among their largest installations. San Francisco and Los Angeles are both laid out on a basis of 100,000 lines. The former has already four exchanges with three at Oaklands, across the bay, most of them of 10,000-line capacity. Los Angeles has six main and four branch exchanges equipped for 25,700 lines. These exchanges are on the common battery system.

The Chicago system is just being brought into use, and is said to be suitable for 1,000,000 lines.

The greater number of exchanges are on what is known as the 3-wire system, the signalling being over the two wires alternately with earth return, but in San Francisco, and other later exchanges, all signalling is effected by the intermittent opening of the circuit at the subscriber s instrument. This has greatly simplified the subscriber's instrument.

All the facilities given on a manual exchange are now repeated on the automatic, and in some instances with a greater degree of flexibility. Junction working is practically eliminated. The ringing of the called subscriber is automatic. Calls are metered or registered (the system, however, gives free or unregistered calls when talking to officials, etc.). Party lines are efficiently dealt with, and also private branch exchanges.

In a cosmopolitan city the advantage seems to be with the automatic as regards operating by the public.

The objection is commonly urged that the subscriber cannot be trusted to operate the switch correctly, and that he should not do more than lift and replace the receiver, all operating being done by a trained staff. This opinion, I think, is only held by a few enthusiasts now. The public are being educated more and more to help themselves by automatic stamp and ticket delivery machines, and the like.

The subscriber's instrument may be of any of the well-known patterns fitted with a dial switch. The switch has finger holes near the circumference into one of which a finger is placed and the dial revolved until the finger comes against a stop.

Fig. 4 shows an instrument with the small circular switch for opening the line only. Under each of the finger holes is placed a figure, 1 to 9, then 0, and any number is made up by inserting the finger successively over the figures that go to make up the number wanted and pulling the dial round. If 637 be wanted, the finger is placed over 6, and the dial revolved to the stop, then 3 and 7 are

similarly dealt with. In the 3-wire system this dial, as it revolves, intermittently earths one or other of the wires, and thus completing a circuit from a central battery causes step by step electromagnetic mechanism to perform certain functions. In the later system these functions are now performed by the dial simply intermittently opening the circuit which has been completed by lifting the receiver.

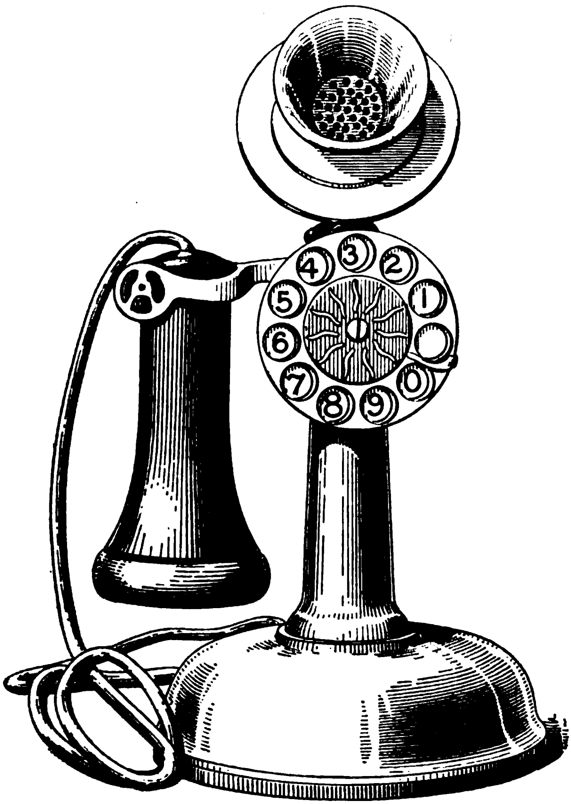


FIG. 4.—Table Pattern Instrument.

Fig. 5 shows a general view of a "connector" (the essential piece of mechanism of an automatic exchange), and Fig. 6 the diagram of connections. A small exchange might be composed only of connectors, one being provided for each line. On a frame of non-magnetic material a vertical shaft is mounted, free to lift upward and revolve. The upper part of the shaft has teeth cut round it, and below this are other teeth in the line of shaft, 10 teeth in each case. The shaft is raised and rotated by electromagnets. One, called the vertical magnet, acts

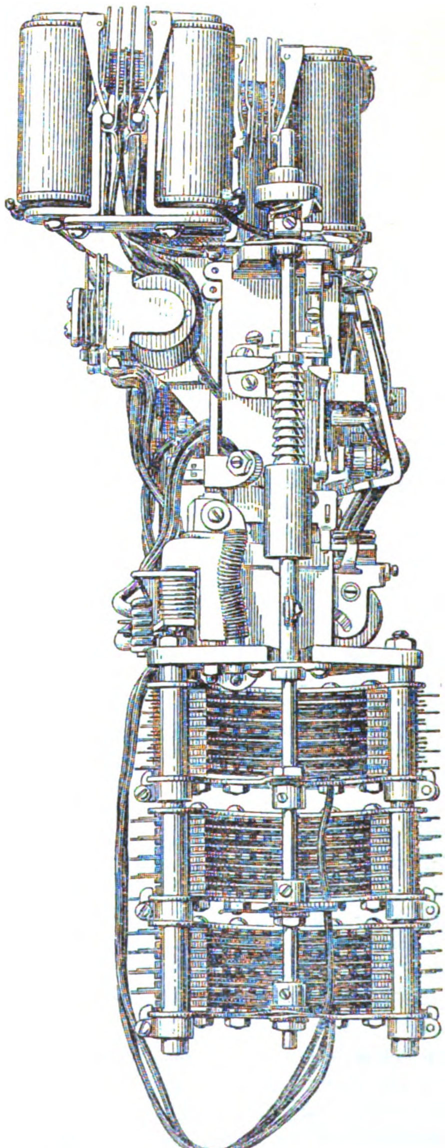


FIG. 5.—Common Battery Connector.

on the teeth surrounding the shaft, and lifts the shaft to a height corresponding to the number of impulses sent, and the number of impulses depends on the second last figure of the number required, *e.g.*, if the number were 67, then the shaft would be raised to the height of 6 teeth. Another magnet would then be switched into action and it would act on the teeth in the line of the shaft and rotate it, the distance depending again on the number of impulses sent; in the case of the number 67 the shaft would be rotated a distance of 7 teeth. The shaft at the bottom has attached to it, and insulated from it, and from each other, contact springs or wipers, which, brush fashion, wipe over contacts associated with the lines to be called. These banks of contacts are arranged in an arc of a circle, and each line bank has 10 pairs of springs in the height, usually in two groups, and 10 contacts horizontally in the arc, wiped over by two twin contact arms. In these contacts are terminated 100 lines. A second bank is placed above this having 10 contacts in the height and 10 in the arc. These are connected to the test, or line engaging circuits, which are purely local and correspond to the wires connecting the jack bushes together in a manual exchange. As the shaft rises vertically step by step, the wipers come to rest in line with the contact levels, so that when the shaft is then rotated the wipers brush over the intervening contacts in the arc, until the wipers come to rest on the contacts of the line required. When the receiver is replaced after a conversation, both wires are earthed simultaneously, or, the circuit is opened, allowing a release magnet to operate on the "dogs" (which maintained the shaft in the position brought about by the electromagnets already described), when the shaft is rotated in the reverse direction by a coiled spring until it is free to fall by gravity to the normal position.

On reference to Fig. 6, it will be noticed that these magnets are in local circuits and are controlled principally by two relays across the line circuit, and through the windings of these two relays the current for the microphone of the calling subscriber is fed in the well-known manner. (The current for the called subscriber's microphone is fed through another pair of coils on the opposite side of condensers.) One line relay is known as the vertical relay, and the other as the rotary; actually the former relay controls both the vertical and rotary movements, the latter relay being the circuit changing or switching relay. An important adjunct of the connector is the side switch which is controlled by the private magnet. This is a four-lever three-position switch.

Reverting again to the dial on the instrument, it should be mentioned that after every series of impulses corresponding to the figure of the number sent over the vertical relay wire, one impulse is sent over the opposite wire which actuates the circuit changing relay which controls the private magnet, so that this extra impulse causes the side switch to step one position after each figure, first to change from the vertical to the rotary electromagnet, and secondly to join the lines through. When the two lines are connected the circuit is

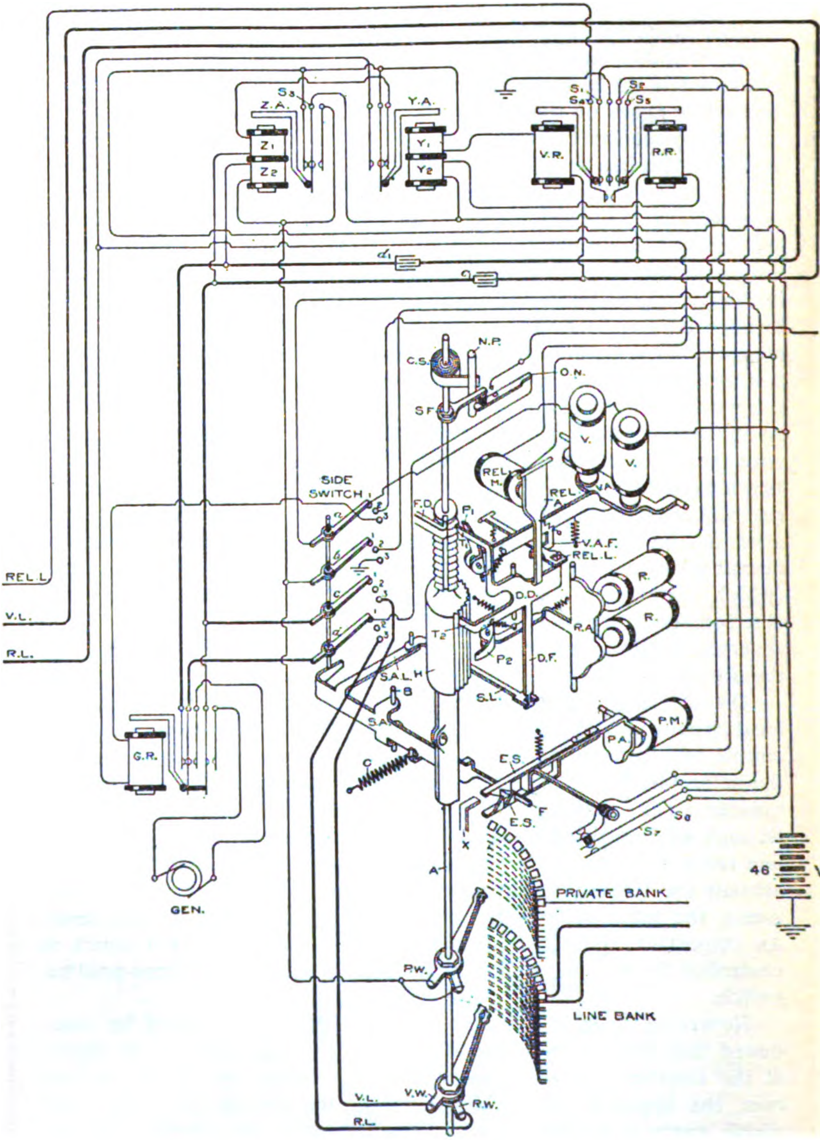


FIG. 6.—Common Battery Connector with its Circuits.

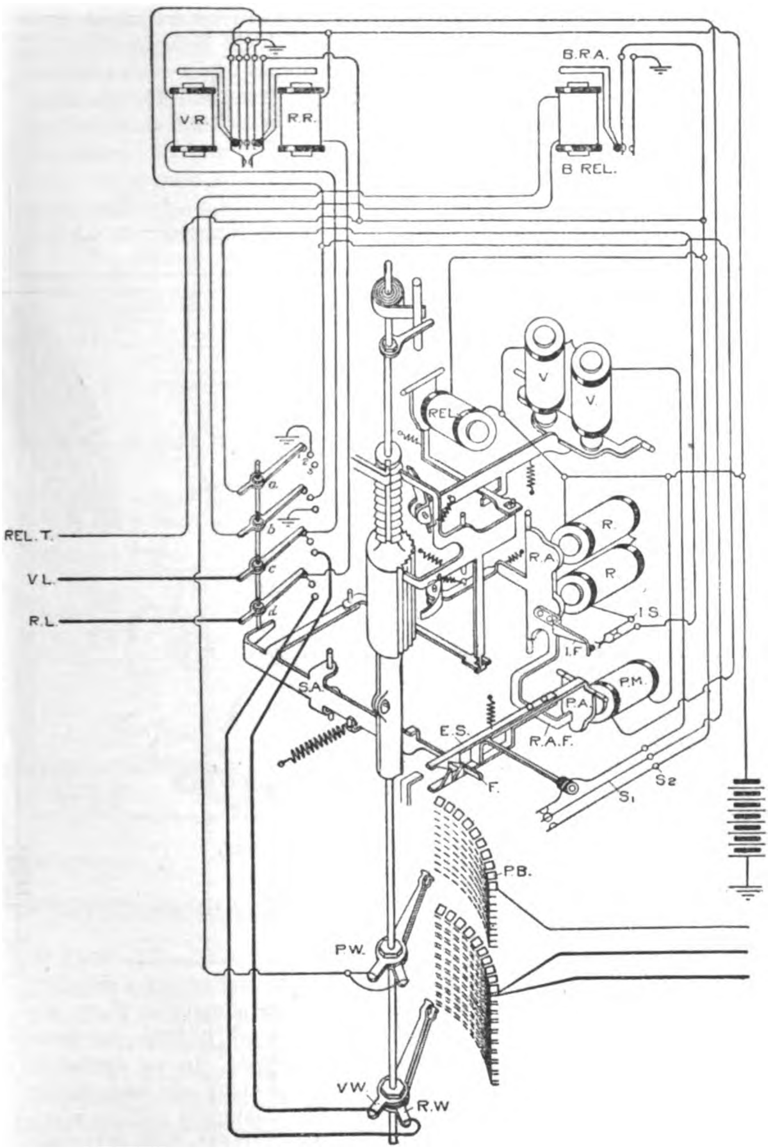


FIG. 7.—Diagram of Selector Connections.

a clean straight one, all switching apparatus being cut out of the circuit.

Should the line be already engaged this will be indicated by a vibrating tone in the calling receiver. This is brought about as follows: When the shaft is rotated the upper wiper puts earth on the local test circuit. Should another line now call for the same number the private wiper will make contact with that multipled tag while the side switch is in the second position, and this earth will complete a circuit through the release magnet, and release the shaft so that it returns to the normal position. When the subscriber rings the shaft will be again lifted, and this allows two springs to make contact

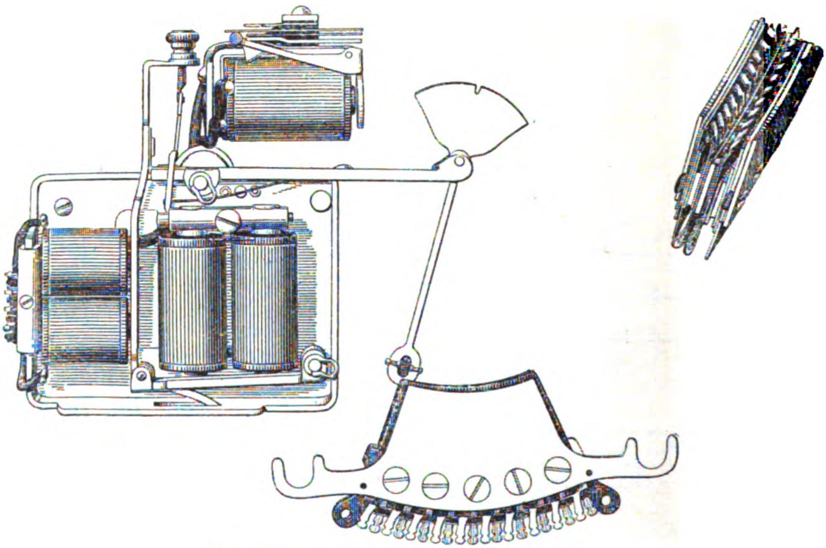


FIG. 8.—Keith Line Switch (3-wire).

which connect with the ringing current through a special interrupter which gives the engaged signal.

For an exchange from 100 to 1,000 lines a "selector" is fitted in addition to the connector. Fig. 7 shows the connections of a selector. This is very similar to the connector, but rather simpler as there are fewer relays, and after it has performed its work it joins the lines through and leaves no electromagnets attached. In its operation it differs from the connector in that after the shaft has been raised due to impulses from the dial it rotates automatically until a junction line is found to a disengaged connector. This is brought about as follows: After the dial earths over the vertical line have raised the shaft, and the earth on the rotary line has actuated the private magnet P.M. which has moved the side switch to the second position,

a local circuit is completed from earth through lever *a* of side switch through contact I.S., through electromagnet R to battery and earth. The shaft is rotated one step and the armature P.A. is depressed by the extension R.A.F. If that line to a connector is idle (*i.e.*, insulated) the P.M. will move the side switch to the third position when the line will be joined through. Should, however, the first connector line be engaged the armature P.A. will be held down, as a circuit is completed from earth on private bank (due to engaging

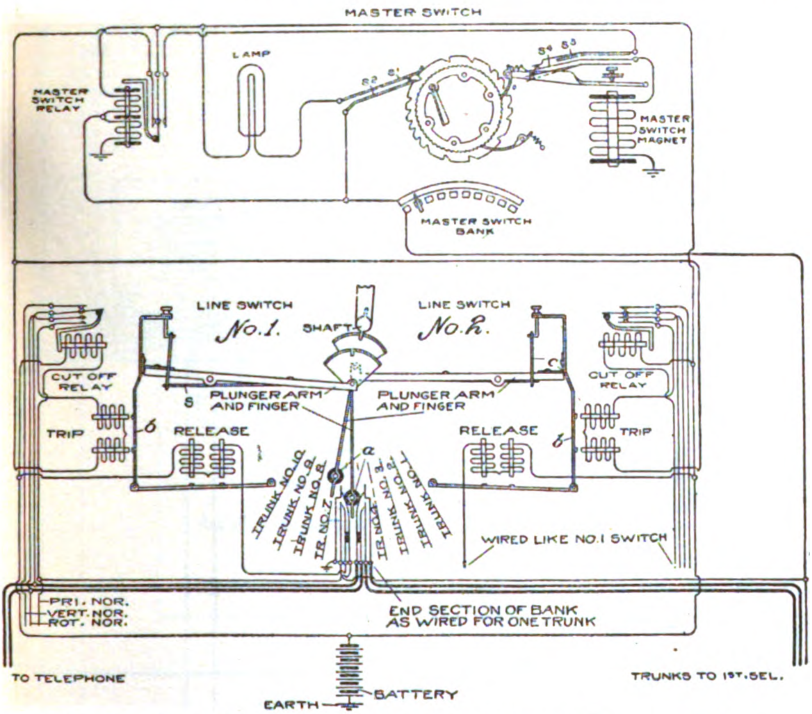


FIG. 9.—Two Adjacent Line Switches, with Graphical Representation of Master Switch.

selector) through P.W. coil of B relay, side switch lever *b* in second position and P. M. coil to battery and earth.

The electromagnet R.I. attracting its armature R.A. by finger I.F. opens the circuit at springs IS, so that the armature is released. The armature is reattracted, and this movement continues, rotating the shaft until the wipers engage with an idle line, when the private magnet armature P.A. is released and moves the side switch to the third position, when the lines are joined through. The selector is then entirely cut off from the lines, these being joined straight through.

A Keith "line switch," Fig. 8 (Fig. 9 shows the circuits), is now

introduced between the subscriber's line and a selector. This is a most ingenious device to avoid the necessity for having an expensive

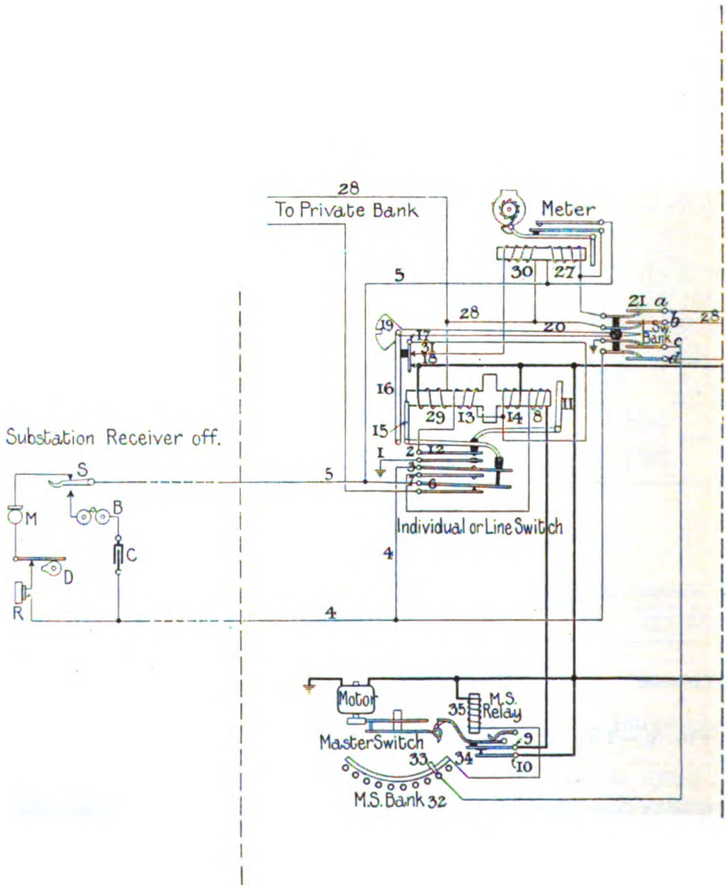


FIG. 10 (*First Part*).—Diagram of 2-wire System, 1,000-line Exchange.

selector associated with each line. Each circuit has its line and cut-off relay, like the manual exchange, and a release relay. These are arranged on each side of a vertical moving shaft in groups of 25, 12

on one side and 13 on the other. This shaft is pivoted and has a backward and forward movement. Each relay has a pivoted arm, or

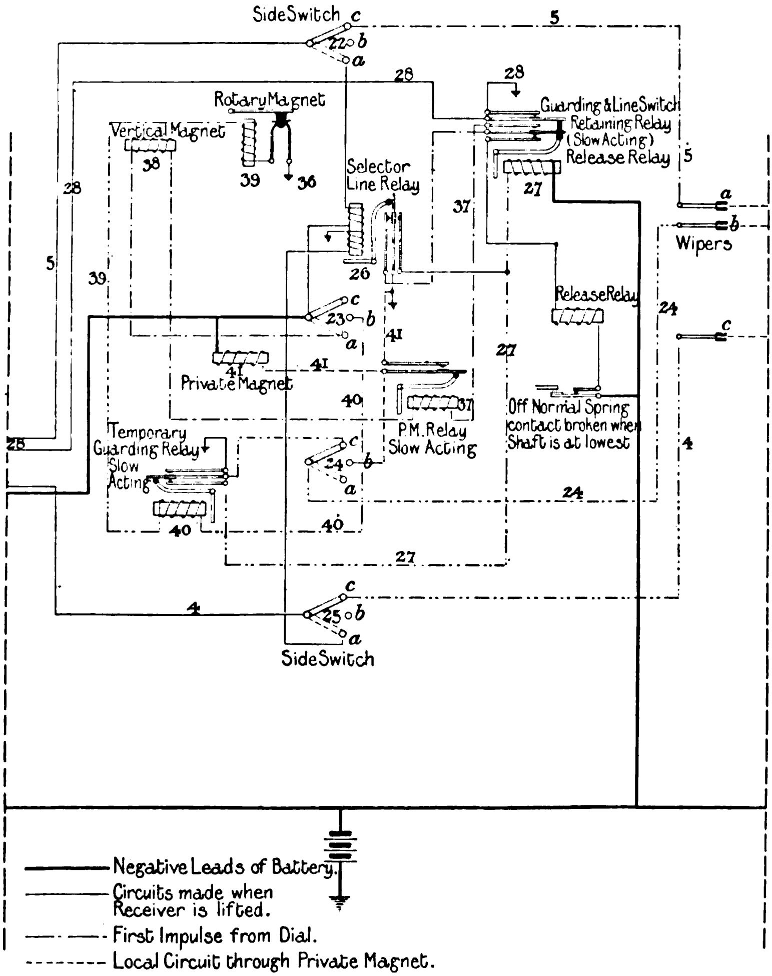


FIG. 10 (*Second Part*).—Diagram of 2-wire System, 1,000-line Exchange.

plunger, whose fan-shaped end has a notch which engages with the moving shaft normally. As the shaft moves it carries with it the plungers and causes them to move on their pivots, so that the point,

which carries an ebonite roller, is moving in front of sets of springs. One bank or level of 10 groups of springs is in line with each plunger.

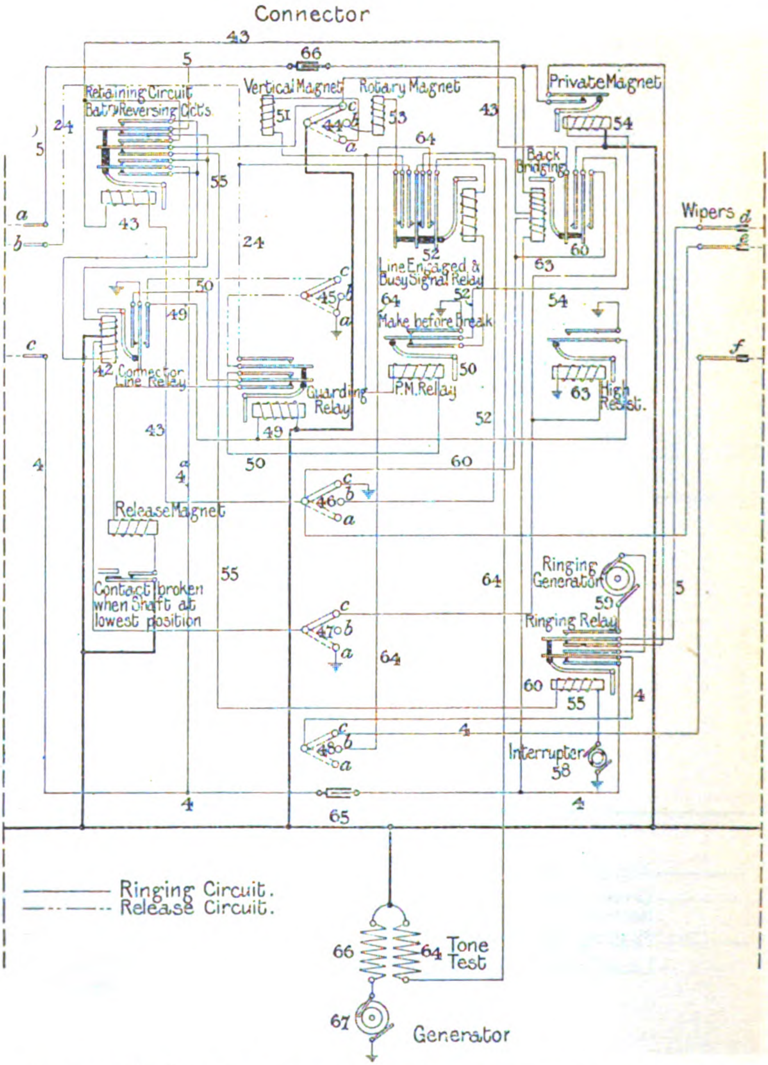


FIG. 10 (*Third Part*).—Diagram of 2-wire System, 1,000-line Exchange.

The corresponding groups of springs in a unit are multipled together and connected to a selector. The unit is usually made up of four sections of 25, with which 10 selectors are associated, and the shaft

is rocked by a master electromagnet. When the telephone is removed, and before the dial is touched (on 2-wire system, first down-

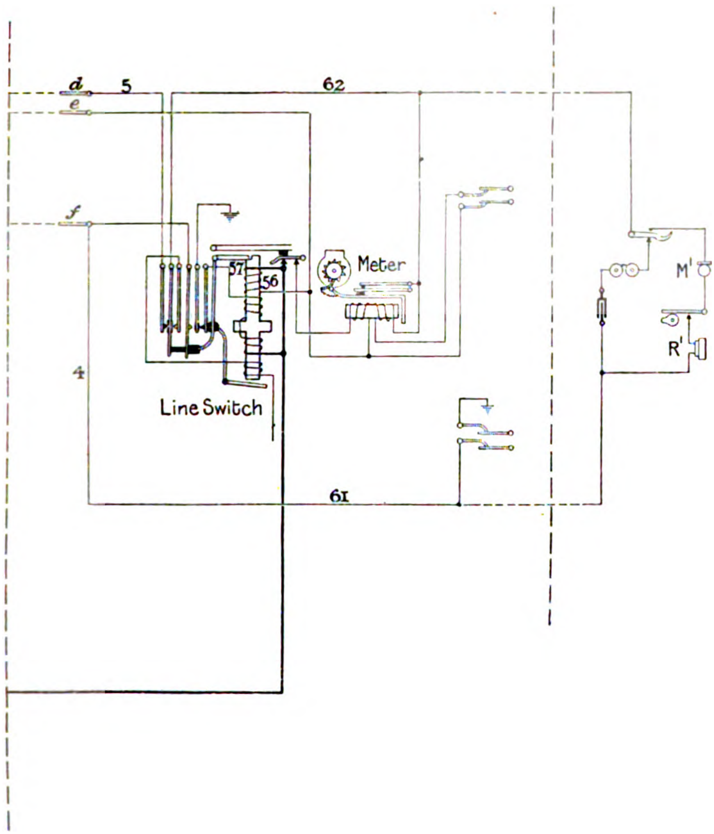


FIG. 10 (*Fourth Part*).—Diagram of 2-wire System, 1,000-line Exchange.

ward movement on 3-wire dial), the line switch is operated automatically. The line or tripping relay has disengaged the plunger arm, and a spring drives the plunger into a group of springs, and also disengages

it from the shaft, so that the subscriber's line has been extended to a selector, at the same time local circuits have been completed through the cut-off relay and the master switch electromagnet, so that the shaft is moved one step and the remaining 99 line relay plungers are opposite the No. 2 selector group of springs. The next call will engage No. 2, and the remaining 98 will then be carried opposite No. 3, the selector being thus always pre-selected. As the plungers become free the shaft picks them up on its return journey.

In the 2-wire system the mechanism is very similar to that of the 3-wire, but the electromagnets or relays controlling these are different. Advantage is taken of the slow-acting characteristic of relays having a mass of copper attached, so that two relays in series are actuated by the first completion of the circuit, but only one responds to the dial impulses.

The three relays of the line switch are now combined, in a most ingenious manner, into one having three armatures. The 2-wire circuits of a 1,000-line exchange connection are shown in Fig. 10. The master switch is shown controlled by a spring which is kept wound by a small motor, but the arrangement shown in Fig. 9 is still generally retained. In these circuits the system of registering calls when the wanted subscriber answers is shown, and it will be noticed that the connection circuits are considerably complicated thereby.

Circuits of 2-wire System.

When a receiver is removed to initiate a call :—

(1) A circuit is completed from earth 1, springs 2 and 3, line 4, receiver R, microphone M, line 5, springs 6 and 7, winding 8, springs 9 and 10 of master switch relay to battery. Armature 11 is pulled up and

(2) Completes a circuit from earth 1, springs 2 and 12, through windings 13 and 14 to battery, and armatures 15 and 16 are attracted.

(3) Armature 15 causes springs 3 and 6 to break contact from springs 2 and 7 and cuts the winding 8 from line. (The armature 11 is, however, momentarily retained by winding 14 until another circuit is completed, when armature 16 short circuits winding 14 by contact 17 and 18). Armature 16 carries the plunger 20, which normally engages with the moving vertical bar. When armature 16 is attracted, therefore, the plunger 20 is forced forward until the insulated disc, passing between the springs in the bank, causes them to make the contacts shown at 21.

(4) Line 4 is then extended by contacts *d* of bank springs 21 and by contact *a* of side switch 25, through one winding of selector line relay 26 to earth. Line 5 is extended through meter winding 27, contact *a* of bank springs 21, through contact *a* of side switch 22, through other winding of line relay 26 to battery, and the line relay is energised.

(5) This in turn closes the circuit through the guarding relay 27, which energising

(6) Completes a circuit from earth 28, through upper contact of

relay 27, contact *b* of bank springs 21, winding 29 of line switch magnet to battery, and this circuit maintains the line switch energised after winding 14 has been short-circuited.

(7) Relay 27 also completes a circuit by line 28 through contact *b* of bank springs 21, through meter winding 30, contact 31, spring 17, and contact 18 of line switch to battery. As current is then through both windings in opposite directions the meter is not actuated.

(8) Relay 27 also puts earth on the wire 28 to the private bank to engage the line.

(9) When the plunger 20 enters the group of springs 21, a circuit is also completed from earth by the contact *c*, through the master switch bank contact 32, by bridge 33 to common connector 34, relay winding 35 to battery. All line plungers are, therefore, rotated to the next disengaged contact or junction by the relay 35 attracting its armature and allowing a spring (motor controlled) to revolve the shaft. Battery is also cut off all lines at springs 9 and 10, so that no call can be made whilst the shaft is rotating.

(10) By the removal of the receiver only a subscriber's line has, therefore, been extended to a first selector by a junction line preselected; the line switch has been cut off the line circuit and is retained operated in a local circuit; one coil of the meter remains (for the present) in circuit in one wire; the calling line has had an engaging current connected to the private bank; the master switch has carried all the line switches of a group opposite the next junction to a first selector. The circuit is now ready for the dial impulses.

(11) Suppose the number wanted to be 734. With the finger in hole 7 the dial is revolved to the stop and the circuit at the instrument is opened 7 times. The selector line relay 26 is de-energised momentarily 7 times. The release relay 27 is slow acting and does not de-energise.

(12) Relay 26, therefore, completes a circuit 7 times from earth on middle spring, under contact, through lower back contact on relay 27, line 37, through winding of private magnet relay 37 (which is slow acting and, therefore, remains energised after the first impulse), through winding of vertical magnet 38, through side switch 23 by contact *a* to battery. The vertical shaft therefore lifts the wipers to the seventh bank level.

(13) Private magnet relay 37 when energised, by its springs, completes a circuit through the private magnet 41. The P.M. relay 37 de-energises after the seventh impulse, in turn de-energises the P.M. 41, and allows the side switches to pass to the second position, when

(14) Another circuit is completed from earth 36, contact springs and winding of rotary magnet 39, through winding of guarding relay 40, through side switch 23 by contact *b* to battery. The wiper shaft is, therefore, rotated one step, and the wipers come to rest if that connector line is free. The rotary magnet 39 closes mechanically the armature of the private magnet 41 and also opens the circuit as shown at 39 by separating the springs. The armature of 39, therefore, falls

back and the armature of the private magnet 41 also, and allows the side switches to pass to the third position.

(15) If, however, the first connector circuit on that level is engaged, a circuit will be completed from earth through *b* wiper, line 24, through side switch 24 by contact *b*, through P.M. 41 to battery. The armature of P.M. 41 therefore remains attracted. The armature of the rotary magnet 39 is reattracted and continues vibrating, at the same time moving the wiper *b* from contact to contact until a free line is obtained, when the P.M. 41 armature falls back and allows the side switch to pass to the third or *c* position.

(16) The calling subscribers line (wires 4 and 5) are then connected to the selector wipers *a* and *c*; all selector electromagnets are cut off the line circuit, and the apparatus is maintained in the through position by the wiper *b* completing a circuit from earth through wire 24, side switch 24 by contact *c*, under contact of relay 40, line 27, through winding of release relay 27 to battery.

(17) When the selector wipers *a* and *c* make contact with the line tabs on the bank, the wires 5 and 4 are extended through the two windings of relay 42 to battery and earth, and this relay is immediately energised as the circuit is completed through the calling instrument. The wire 4 is extended by line switch bank 21, contact *d*, side switch 25 in *c* position, wiper *c*, line 4 and 4*a* bottom contact of relay 43, lower winding of relay 42 to side switch 47 by contact *a* to earth. The wire 5 by line switch bank 21, contact *a*, side switch 22 in *c* position to wiper *a*, by upper under contact of relay 43 to upper winding of relay 42 to battery.

(18) Relay 42, when energised, completes a circuit from earth by back contact, through winding of relay 49 to battery.

(19) Relay 49 completes the retaining circuit (relay 27) to earth from wiper *b* of selector, through upper back contact of relay 49 to side switch 45 by contact *a* to earth. Relay 49 is slow acting and does not de-energise when impulses are sent through relay 42.

(20) No. 734 is being called, and so far the seven impulses have only been sent. The finger is now placed over figure 3 and the dial revolved, and the circuit at the instrument is opened 3 times, and the relay 42 pulsates 3 times.

(21) A circuit is completed 3 times from earth by under contact of relay 42, back contact of lower group of springs relay 49, line 50, through winding of P.M. relay 50, winding of vertical magnet 51, side switch 44 by contact *a* to battery. The vertical magnet, therefore, lifts the shaft with the wipers to the third bank level.

(22) At the same time P.M. relay 50 has been energised and completed a circuit from earth by back contact of relay 50, through winding of P.M. 54 to battery, and P.M. has been actuated and has opened the line circuit.

(23) Relay 42 remains energised and the circuit of the private magnet relay 50 is, therefore, broken; the private magnet 54 circuit is likewise broken, and it returns to normal, allowing the side switches to pass to the second position.

(24) The finger is then placed in the hole over the figure 4 (the last figure of the number 734) and the dial revolved. Relay 42 is again actuated 4 times, completing a circuit 4 times from earth, by back contact of relay 42, back contact of lower group of springs 49, winding 50 of private magnet, outside under contact of relay 52, rotary magnet 53, side switch 44 by contact *b* to battery. The rotary magnet 53, therefore, moves the wipers to the fourth group of springs of the connector. P.M. relay 50 again de-energises, and if the line wanted is idle, the private magnet 54 is also de-energised and allows the side switch to pass to the third position.

(25) The wire 4 of the calling line is then joined through condenser 65, under contact of relay 55, side switch 48 by contact *c*, to wiper *f* and one side of the called line; and wire 5 of the calling line by condenser 66, the contact of P.M. 54, and the upper under contact of relay 55 to the wiper *d* to the other wire of the called line, and a guarding potential or engaged test is placed on the line called at wiper *e*, from earth at side switch 46 by contact *c*, wiper *e*, winding 56 of line switch of called line to battery.

(26) The line switch is energised, the armature 57 being attracted, and the circuit completed from wiper *d* by line 62 to the telephone, and the line switch coils cut off from the line called.

(27) The side switch 44 in the third position completes a circuit from earth through interrupter 58, ringing relay winding 55, line 55, through central under contact of relay 43, through side switch 44 by contact *c* to battery and relay 55 is energised.

(28) Relay 55 cuts off the calling line and intermittently connects the called line to the ringing generator 59.

(29) When the receiver is lifted to answer, a circuit is completed from earth, through side switch 46, by contact *c*, lower winding of relay 60, lower under contact of relay 55, side switch 48 by contact *c*, to wiper *f*, line 61, receiver R^1 and microphone M^1, switch hook upper contact, line 62, outer contact of line switch, wiper *d*, outer under contact of relay 55, contact of relay 54, to upper winding of relay 60, side switch 44 by contact *c* to battery. Relay 60 is therefore connected in bridge across the called line and is energised, and current is fed through the windings for the microphone M^1.

(30) Relay 60 completes a circuit from earth, through side switch 46 by contact *c*, relay winding 43, line 43, left-hand contact of relay 60 to battery. Relay 43 is energised, and a retaining circuit is then completed from winding 43, through middle upper contact of relay 43, through side switch 44 by contact *c* to battery.

(31) Another circuit is completed by relay 60, from earth by side switch 46 by contact *c*, line 60, line 63, through right-hand back contact of relay 60, to side switch 47 by contact *c*, to lower winding of relay 42, so that the resistance of relay winding 63 is cut out of circuit.

(32) Relay 43 when actuated as described in (29) reverses the connections between the called line and relay 42, the circuit now being

from earth at side switch 46 by contact *c*, back contact of relay 60, side switch 47 by contact *c*, lower winding of relay 42, outer upper contact of relay 43, to the *a* wiper of the selector, line 5, through calling instrument, back by line 4 and *c* wiper of selector, lower upper contact of relay 43, to upper winding of relay 42, to battery.

(33) It will be remembered that current is through both windings 30 and 27 of the meter, but in such directions that they neutralise. The reversal of the current, by relay 43, now causes this to actuate and register. The meter contact closing short circuits the winding 27 and the meter is retained in the energised position by the local winding 30. No action of either of the subscribers, therefore, can cause it to operate more than once.

(34) Relay 63 is used in semi-automatic systems. Being first connected in series with the lower winding of relay 42 and then shunted by relay 60, additional current is sent to line, which may be utilised to operate a supervisory signal on a cord circuit. Being of considerable resistance, and to prevent trouble should relay 42 fail to act, the earth on back contact keeps relay 49 actuated.

(35) When conversation is finished and the circuit opened by replacing the calling subscriber's receiver, relay 42 is de-energised. This opens the circuit of relay 49 of the connector and relay 27 of the selector, and both complete a circuit through the associated release magnet. The former from earth and under contact of relay 42, under contact of relay 49, through release magnet winding and contact to battery. The latter from earth and under contact of relay 26 to under contact of relay 27, through release magnet winding and contact to battery. The release magnets attract the dogs and thereby release the wiper shafts which are revolved by the controlling springs, until they fall by gravity to the normal position. In this position the release magnet contacts are open and cut off the battery. All circuits are broken and apparatus returned to normal position for calling.

(36) Should the line called for be engaged there will be a guarding potential on the private bank of the connector. This circuit in the connection just described, is from earth at side switch 46 at contact *c*, to wiper *e*, through winding 56 of individual switch, to battery.

(37) Another connector wiper now making connection with the same line by a multipled bank contact, will complete a circuit from earth by side switch 46 (contact *c*), wiper and bank contact *e* of the engaged line, contact bank and wiper e^1, side switch 46^1 by contact *b*, middle under contact and winding of relay 52^1, under contact of P.M. relay 50^1 (lines 52 and 54), private magnet winding 54^1 to battery, all on connector of the line attempting to call the circuit already engaged.

(38) With the result that the private magnet 54 opens the circuit of the calling line, the other wire from wiper *f* is open at the side switch 48 contact *c*.

(39) Relay 52 energising also closes its middle outer contact so that the circuit of relays 54 and 52 is completed by upper back contact of

relay 49 to side switch 45 by contact *b* to earth (to further safeguard the line attempted to be called).

(40) The contact nearest the winding of relay 52 is also closed, and a circuit is completed from the secondary circuit of the busy signal machine 64, line 64, make contact of relay 52, side switch 48, by contact *b*, bottom under contact of relay 55, through condenser 65 over wire 4 and through calling instrument, and back by wire 5 to outer under contact of relay 43, upper winding of relay 42, and by common battery lead to the busy signal secondary winding.

(41) The busy machine primary circuit 66 is from earth through interrupter 67, winding 66, through battery to earth.

(42) When the receiver is replaced after the busy signal is heard all apparatus is returned to the normal condition.

(43) If the line with which connection is desired originated the call, the engaging circuit will be from the selector earth 28, upper outer contact of relay 27, contact *a* of line switch bank, winding 29 of line switch to battery, with a branch to the private bank contact.

When an exchange is over 1,000 and up to 10,000 lines, a second selector is added—Fig. 11 (3-wire system). When a capacity of 100,000 lines is required, a third selector is used, and so on.

We will recapitulate the operation of a 1,000-line equipment. On an exchange of this size there will be 1,000 line switches (*i.e.*, one per line), 100 first selectors, and 100 connectors. It is found in practice that a 10 per cent. basis is ample for ordinary exchanges ; very rarely are there more than 10 connections (or 20 telephones talking) per 100 lines.

After the receiver has been lifted, and before the dial has been revolved to the stop, the line switch has done its work and connected with an idle selector. If the number desired is 865 the caller will place a finger over the number 8 and revolve the dial to the stop. The selector will step up to the eighth level of contacts and come to rest on the first set of contacts if these are disengaged ; if, however, that line to a connector is already engaged, the shaft will continue to rotate automatically until an idle connector line is found. The finger will then be placed over the figure 6, and the dial revolved to the stop, when the connector will step up to the sixth level, but will not make contact with any line. The finger will then be placed over the figure 5, and the dial revolved to the stop, when the shaft will rotate until the fifth group of springs on the sixth level is reached.

When stations below 100 in an exchange of 1,000 lines are called the number is preceded by 0 so that the sequence of operations may remain the same, or the two figure numbers will be omitted.

On 100,000-line systems, instead of using five figures to identify a line, four figures are used preceded by a letter as being easier to remember, and generally the letters indicate different exchange, as the system is usually built up of ten exchanges, or, ten groups of exchanges, each having a capacity of 10,000 lines.

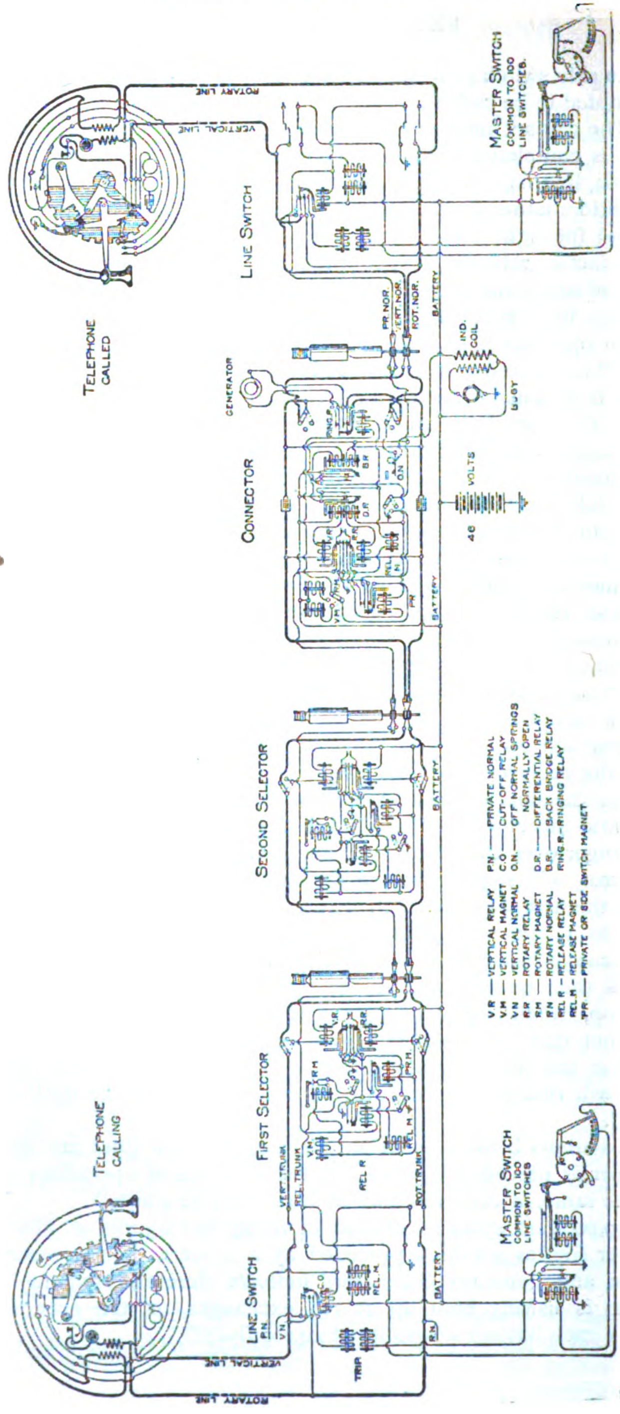
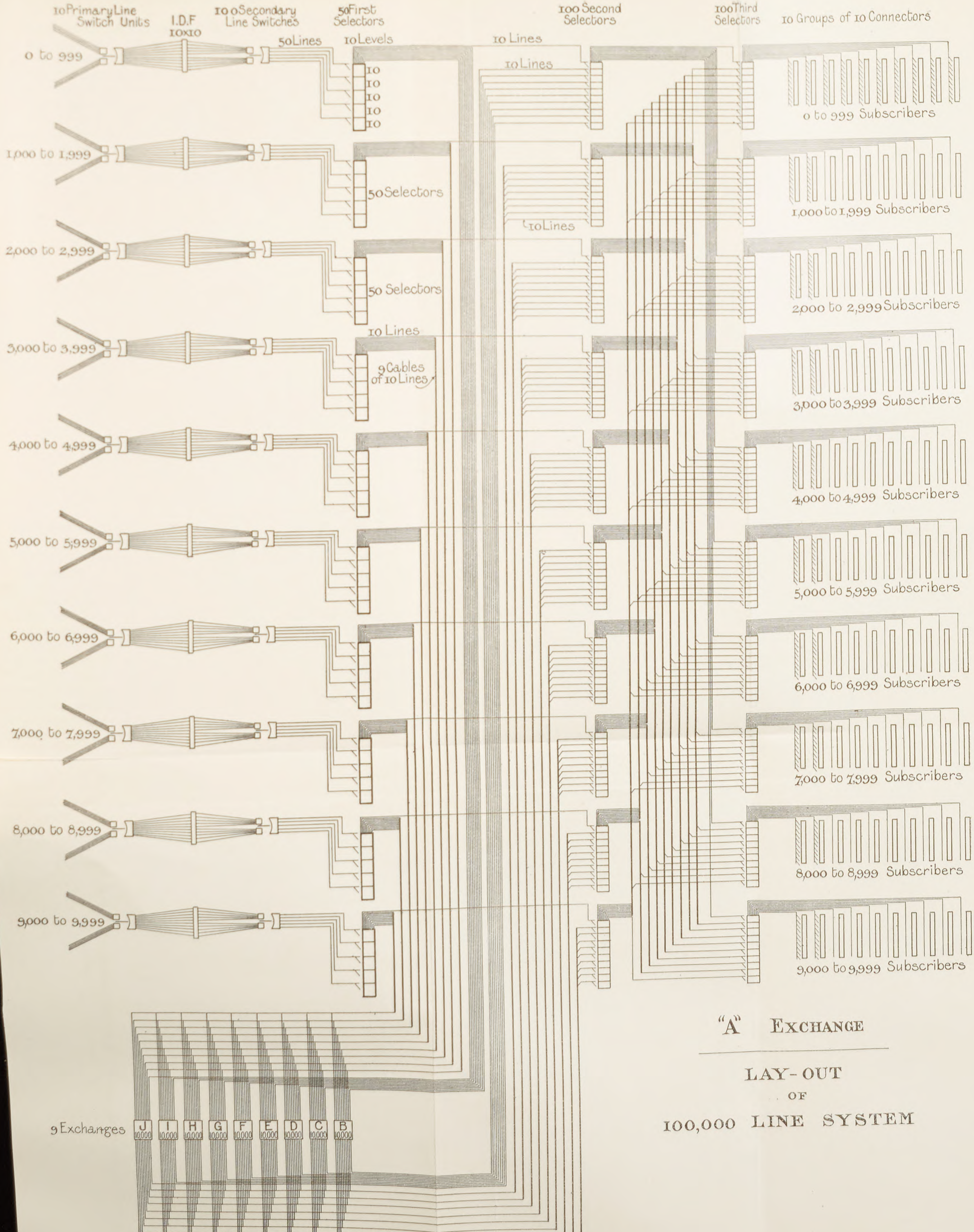


FIG. 11.—Connections of 10,000-line Exchange.



"A" Exchange

LAY-OUT OF 100,000 LINE SYSTEM

Fig. 12.

One level of the bank contacts on a first selector, therefore, will be associated with the local exchange, say Central, the second with North, the third with South, and so on. The line switch having automatically connected with a first selector, the first movement of the dial will cause that selector to pick up a second selector in one of the groups of 10,000 (this second selector, like the first, may have the level connected with a local exchange and each of the other levels connected with sub-exchanges, or all the levels may be connected to different groups of 1,000 in the same exchange) and this in turn will pick up a third selector in a group of 1,000, which will pick up a connector and complete the connection as previously described.

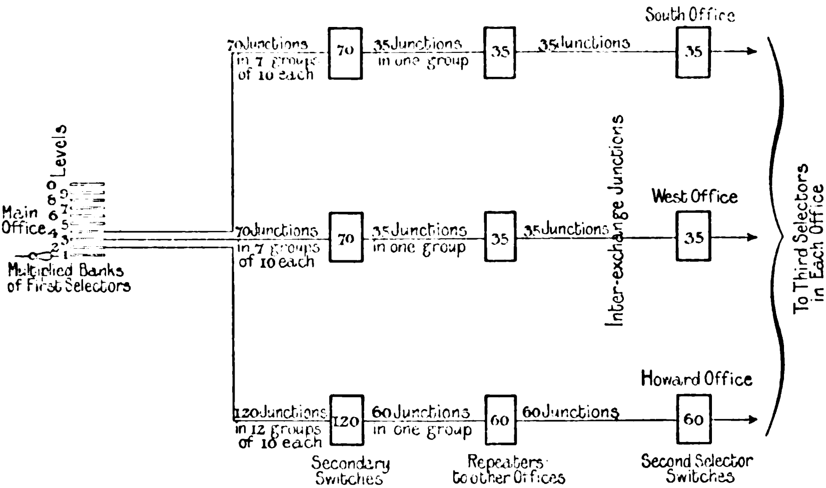


FIG. 13.—Junction Lines, San Francisco.

It will thus be seen that there is no junction working in the sense of special or more complicated operating such as we usually associate with manual exchanges. The 10 per cent. of lines between selectors may be reckoned as junctions, but the operating is uniform whether they are in the same building or connecting exchanges some miles apart. Fig. 12 shows the lay-out of a 100,000-line system.

It has been found in practice that 10 per cent. of lines between first and second selectors in these large installations is unnecessarily high owing to the rapidity of service, and a "secondary line switch" has been introduced to reduce that number. Both line switches act automatically and are quite independent of any movement of the dial. This still further reduces the number of lines between exchanges.

In the diagram the 50 lines from a secondary line switch are shown connected to one group of first selectors for the sake of simplicity. It would be better to connect five lines to each group of first selectors.

To equalise the traffic on the first selectors an intermediate distributing board is introduced between the primary and secondary line switches.

By the introduction of secondary line switches any subscriber's line may use any first selector and any junction line is made available to any first selector.

Fig. 13 shows how junction lines between exchanges are made available to all subscribers. Mr. Arthur Bessey Smith points out that by increasing the number of junctions on a group of secondary line switches, the traffic that may be carried is greatly increased, *e.g.*, if there are only 10 junctions in a group, only 225 busy hour calls or 22·5 calls per junction will be carried, if 20 junctions are in a group 575 busy hour calls or 28·75 calls per junction, whereas

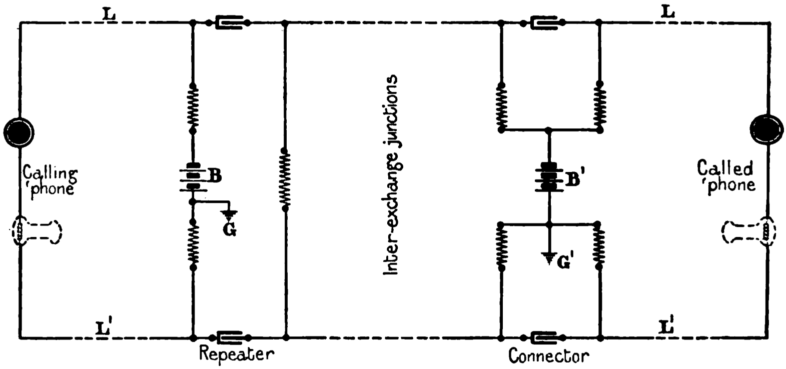


FIG. 14.—Speaking Circuits over Junctions.

if 100 junctions are in a group 4,000 busy hour calls or 40 per junction may be efficiently carried.

Great care has been taken in designing lines between exchanges to balance them, and as will be seen from Fig. 14 the simplified circuit is equal to that on any manual system. The circuits are divided for signalling purposes by condensers, and current for the microphones is supplied from a battery in the exchange at each end of the junction as on manual systems. The repeater is for repeating dial impulses only.

The opinion is commonly held that the automatic system is most inflexible, but quite the contrary has proved the case in practice, and all special services, such as metering or registering calls, party line working, private branch exchange working, etc., are now standardised. On a message rate system the meters are associated with the line switch as already described. It will be readily understood that a free service may be given to the information and other desks, or to any special departments, by not fitting them with the battery re-

versing facilities, and for this purpose these lines are grouped on special connectors.

Party Line Working.—A 4-party frequency system is used with the bells of the subscribers' instruments tuned to respond to frequencies of $16\frac{2}{3}$ cycles, $33\frac{1}{3}$ cycles, 50 cycles, $66\frac{2}{3}$ cycles. A group of party lines will be multipled over four connectors, and to each connector will be supplied ringing current of one frequency only so that when a connector is brought into use only one particular subscriber on the line can be called.

Private Branch Exchanges.—These may be entirely automatic, but are usually preferred to be manual for local service. A switchboard will have several lines to the central exchange, and these are given one number only. These lines are joined to special connectors which have a feature belonging to the selectors that enables them to continue to rotate automatically until a free or disengaged line is made contact with. The connector is made to rise and rotate to the number of the line in the usual way by rotating the dial twice, then if the first line associated with that number is engaged the shaft will continue to rotate until a free line is obtained, or, if all are engaged, then it will go to the contact beyond, which is associated with that group of lines, and is connected up to give the busy signal, so that the subscriber hearing this knows that all lines are engaged.

Call Offices.—These are operated in a simple but very ingenious manner. The subscriber calls in the usual way, but when the called station answers, the reversed current actuates an electromagnet in the coin box which short circuits the microphone and places a shunt about the receiver, so that the caller can but faintly hear the party called. On the insertion of the requisite coin the talking is made normal.

Sub-District Stations.—As already indicated, a great feature of the automatic system is that it is not essential to concentrate a great number of lines in any one building. The system will work as efficiently if 10,000 lines are in one building as in ten exchanges of 1,000 lines each. The apparatus, with the exception of, probably, the power plant, will be exactly similar, but the street cable plant will be very different. Instead of 10,000 lines converging to one centre, there will be, in addition to the shorter converging lines, the 10 per cent. of lines between first and second selectors between exchanges. (This aspect of the system will be dealt with more in detail later.) It will thus be seen how efficiently the automatic system meets the varied needs of a great city, where a residential district of a few years ago with few telephones becomes a busy business centre requiring many telephones, like Finsbury Circus; or when a slum, like the district between Holborn and the Strand, gives place to a great thoroughfare like the Kingsway, and thus upsets all calculations of capacity in underground mains and necessitates the re-opening of streets. In the automatic system a district station of suitable capacity would be opened in such localities and the necessary local lines concentrated on these, and

the existing cables of small capacity to the large exchange would be utilised as junction wires.

A small town with an ultimate capacity of 12,000 to 15,000 lines might be efficiently served by a central of 10,000 lines and several district exchanges varying from 100 to 600 or 800 lines.

In existing manual systems somewhat similar automatic district stations may be used with advantage as valuable adjuncts, either to avoid expensive underground cable work, the provision of new manual plant, or expensive additions to existing plant of limited capacity, and this phase of working deserves more than passing attention. The instruments on such an automatic equipment would be of any of the well-known patterns without any automatic feature whatever. At the district station they would be connected to line switches, such as have already been described, for outgoing work. At the manual exchanges these junction lines would end on the usual line and cut-off relay, answering jack, and calling lamp, or on single cord equipment like manual incoming junctions. On the removal of the receiver to call, the line switch would connect with a disengaged junction instantly, and the line lamp would glow, and the operator would complete the connection in the usual way, the service being absolutely similar to a connection in a purely manual exchange. Fig. 15 shows such an arrangement. For outgoing calls from the manual exchange, an operator would have in addition to the ordinary double cord equipment, a switch to connect up a dial calling device by which, after making the connection, she would call the number required in a manner similar to a subscriber calling on a full automatic system. All the lines in the district station are multiplied on to connector banks to allow of being called. Fig. 16 shows such an arrangement. The above method supposes a complete multiple of the manual exchange to be available. Another method is to multiple the outgoing junctions over the manual board and on to a controlling operator's position which may be away from the multiple. This operator would have a key in each junction to switch in the dial-calling device and a lamp to indicate what lines were engaged. A manual operator receiving a call for a district station number would momentarily connect her telephone to a call or order wire, and inform the control operator the number wanted. That operator would allot a junction to which the manual operator would make connection. The controlling operator would call by the dial and ring the subscriber wanted, and the manual operator would supervise the connection by the cord lamps in the usual way. That withdrawal of the plugs after the clearing signals were obtained will give the signal "junction disengaged" to the controlling operator and automatically restore all apparatus at the district exchange to normal. Fig. 17 shows such an arrangement. It will be readily understood that two district station subscribers can be connected together by the circuits already described by the use of two junctions, one incoming and one outgoing.

Such an important and far-reaching subject as a change from a

manual to an automatic system must be considered very seriously from various points of view. In some countries objection has been raised to the automatic system because it will do away with one form of employment which is very suitable for women; in new countries where women

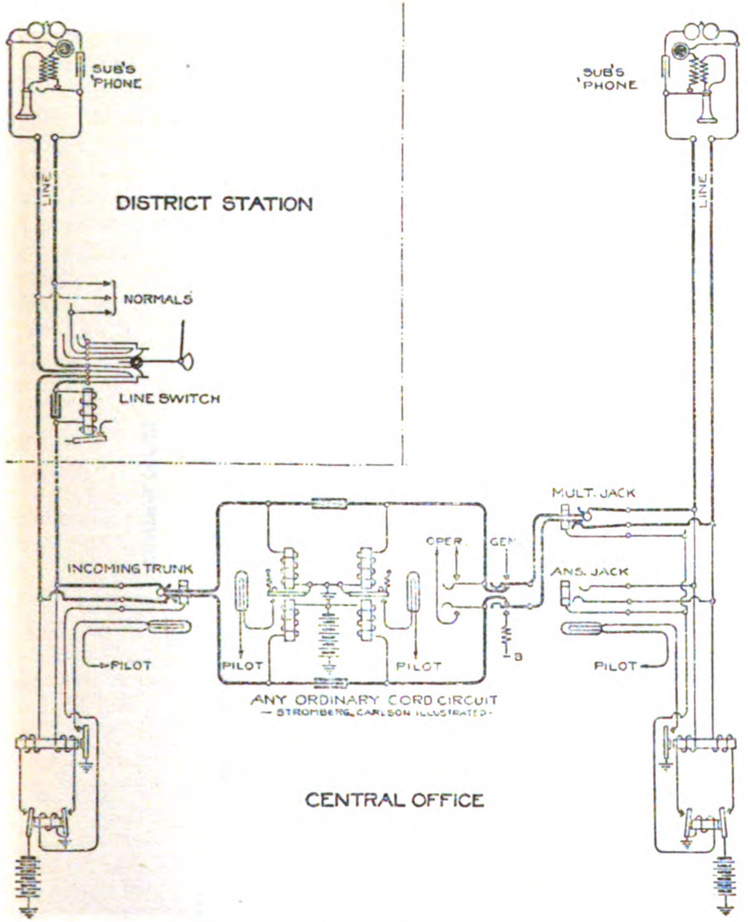


FIG. 15.—District Exchange to Manual Exchange. Diagram of Connections.

are scarce the automatic appeals as a way out of a great difficulty. Considering the question, however, quite apart from sentiment, it will be interesting to investigate it, briefly and generally, from the points of view of efficiency, capital cost, and maintenance.

Efficiency.—The manual system is now as near perfection from an operating point of view as it can be brought, and increased efficiency

can only be obtained by refinements due to more expert operators and thorough supervision. The principle of working is that the subscriber

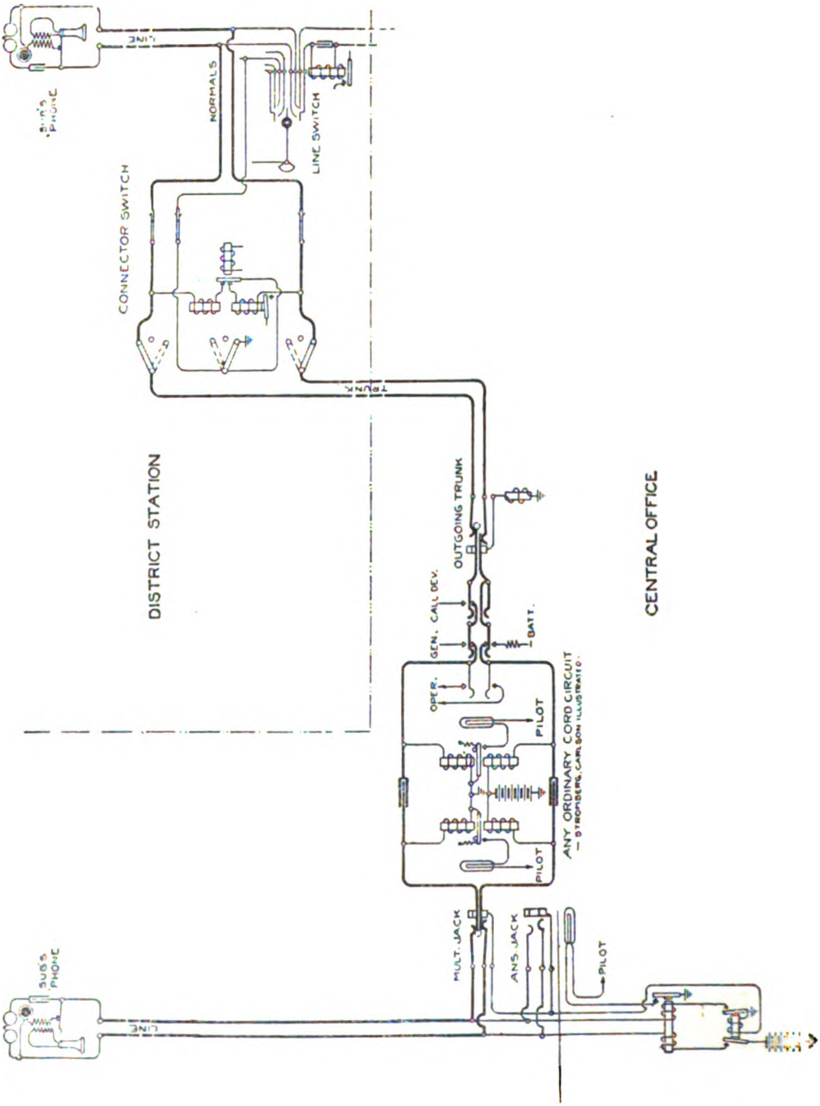


FIG. 16.—Manual Subscriber to District Exchange

should only remove the receiver, state his requirements, and replace the receiver on the switch-hook, all operating beyond being performed by experts. This sounds good and simple, but it depends, first, on

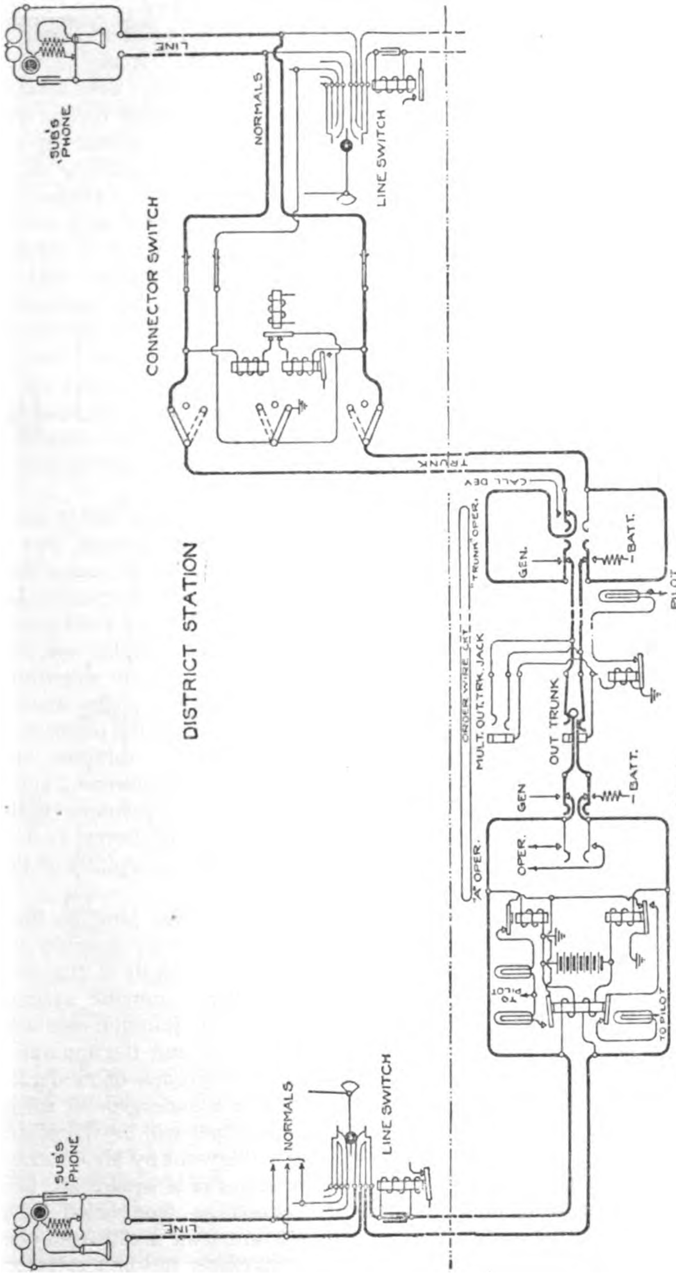


FIG. 17.—Connections of Automatic to Manual Stations.

the articulation of the speaker, who may be from any county or any country, and, secondly, on the ear and understanding of the operator to interpret the words before giving effect to them. Again, in a city like London, something like 75 per cent. of the calls are over junction lines, which means that the first operator has to repeat the number required to a second operator. In the automatic system the responsibility for getting any number, no matter how large, is entirely on the caller. If a blunder is made, the caller has only himself to blame. He is practically asked to spell out his number like a child with picture blocks, and yet some experts say he is not to be trusted to do this. Why, one has seen a horse do as much! It is also claimed that the subscribers on an automatic system answer more quickly, as there is no operator to blame. For rapidity of service the automatic has the advantage unquestionably. As quickly as a caller can spell out his number, so quickly is the connection built up, *for any number on the system*, and the clearing is instantaneous. The time taken to send in a clearing signal on the manual is the time taken on the automatic to disconnect. The secrecy of the conversations will also appeal to many.

Capital Cost.—This for the actual exchange equipment in small exchanges is much more with automatic than with manual, but as they increase in size they approach nearer until at about 10,000 lines they are equal in cost. This is for single exchange equipment, but when the telephoning of a great city is considered, the results may be very different. The subject is, however, a very complex one, and would require very careful study of a particular area to determine exact costs. This may be noted, however, that whereas the manual system increases with an ever-increasing ratio owing to the increase of junction lines with their complicated circuits, huge multiples, and attendant operators, the cost of the automatic system increases much more uniformly. The apparatus increases on the percentage basis, formerly mentioned, and the junction lines are actually fewer, as they carry a greater number of busy-hour calls owing to the rapidity of the service.

Owing to the tendency on the manual systems for junction lines to increase abnormally, as great a number of lines as possible are accommodated in one exchange, and the average length of the subscribers' lines is, therefore, increased. On the automatic system, however, as the working from beginning to end is junction working there is not the same necessity for large exchanges, and the apparatus can, therefore, be broken up and distributed in groups of moderate size as best suits the economical lay-out of an underground cable system. The average length of the subscribers' lines will be, therefore, much less. Fig. 18 shows a suggested or typical lay-out by Mr. W. Lee Campbell. Centrally and at each of the corners of a square are five main exchanges with numerous smaller exchanges connected with each. The line switch and first selector for an outward call from one of the smaller exchanges would be in that office, the first selector

would then pick out a second selector in one of the main exchanges, then, if another sub-exchange was wanted, the second selector would pick out a third selector in that exchange, which in turn would pick out the correct connector on which the number wanted was located. The operating would be exactly the same if all the lines were in one building.

Fig. 19 shows an actual lay-out (at Los Angeles), and attention is drawn to the length of the lines between exchanges.

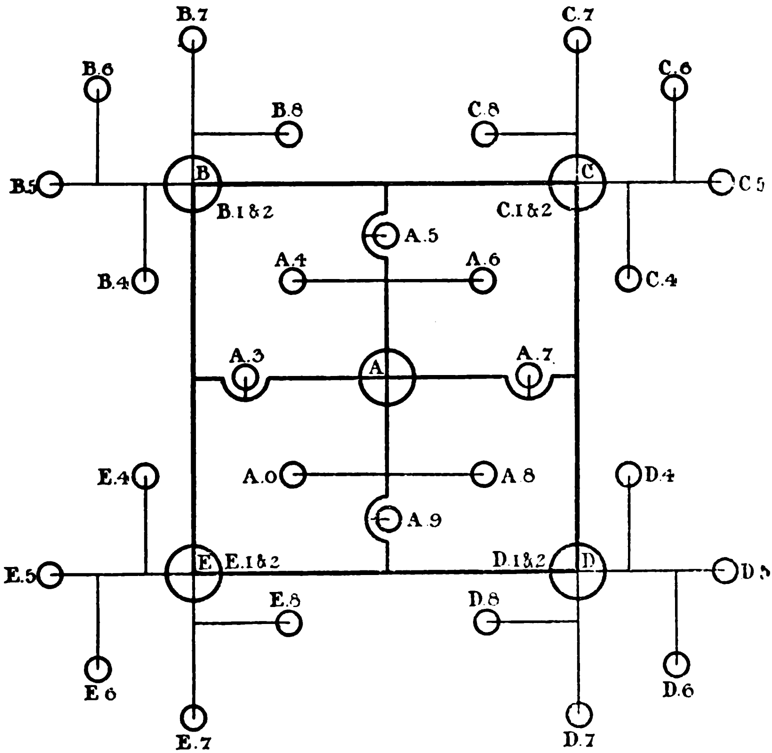


FIG. 18.—Skeleton of Divided 50,000-line Automatic System.

The figures obtainable regarding costs are very few, and they are based entirely on American practice. Mr. W. Lee Campbell (in his paper before the American Institute of Electrical Engineers, June 29, 1908) showed by a series of curves the comparative costs of manual and automatic equipments, and as these have not been challenged they may be taken as at least comparatively correct. Since that time the manual system has increased in cost by the introduction of new features, as the use of three calling lamps and jacks per line, the more general

introduction of keyless ringing, etc., but against this the manufacture of equipment is somewhat cheaper.

In the automatic equipment the introduction of the secondary line switch to reduce the number of first selectors, the use of the same

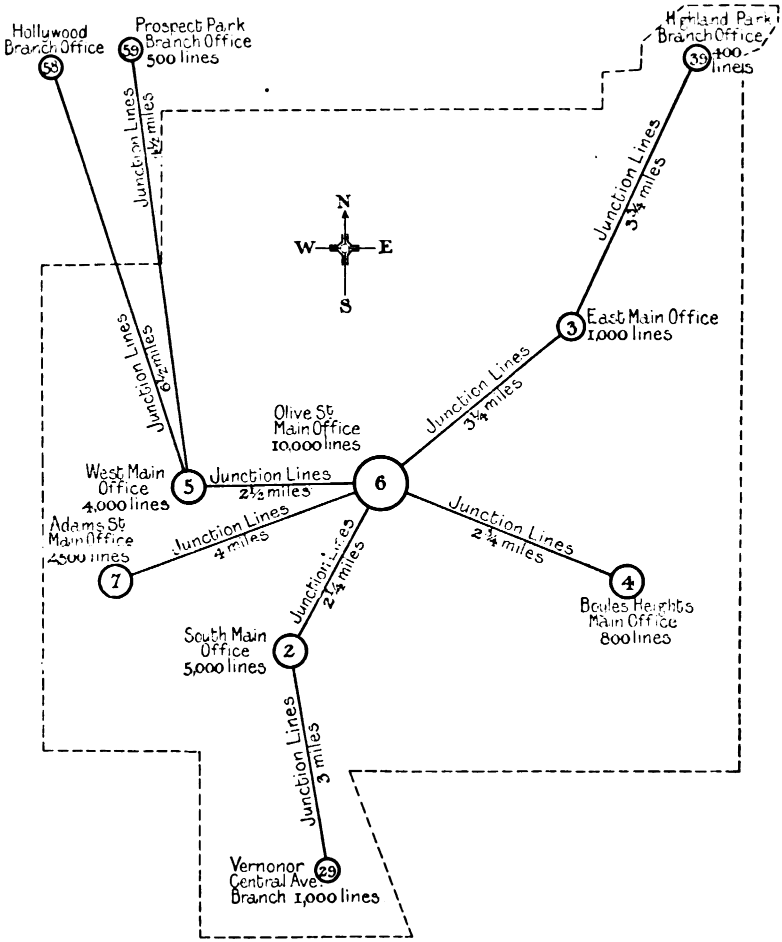


FIG. 19.—Plan of Los Angeles System.

switch to reduce the number of junction lines, the introduction of secondary line switches with banks for a greater number of circuits than ten, has greatly reduced the cost of automatic plant, and particularly the number of underground junction lines to carry the traffic between exchanges.

COMPARATIVE COSTS—MANUAL AND AUTOMATIC SYSTEMS.

	5,000 Lines.		10,000 Lines.	
	Manual.	Automatic.	Manual.	Automatic.
Value per line—switchboard equipment without junctions...	£3 11s. 6d.	£4 3s.	£5	£5
Subscriber's instrument...	£1 15s.	£2 5s.	£1 15s.	£2 5s.
Cubic feet of building	42,000	21,000	88,000	44,000
Square feet floor space	3,700	2,100	7,250	3,750
First cost fireproof building ... ... (Land, furnishings, offices not included) ...	£1,667	£855	£3,500	£1,750
Operating, repairs, maintenance, per line per annum	£1 5s.	8s. 10d.	£1 13s. 6d.	9s. 4d.
Above plus power, light, taxes, depreciation equipment and building renewals (Depreciation of manual taken at 10 years; automatic at 12 years)	£2 1s.	£1 4s.	£2 10s.	£1 5s. 6d.
If manual divided into two exchanges of 4,000 lines and two of 1,000 there will be 115 A operators, 25 B operators, instead of 90 A operators.				
Cost of operating and maintenance of above per line per annum	—	—	£3 10s.	£1 6s. 6d.
Cost per line, switchboard equipment per annum	—	—	£4 14s.	£4 18s.
Cost per line, switchboard equipment and buildings per annum	—	—	£5 4s. 6d.	£5 2s.

The cost of installing, both manual and automatic equipments, will be greater, I think, in this country than in America.

The following schedule of comparative costs for Manual and automatic exchanges of 5,000 and 10,000 lines are taken from the paper referred to.

The cost per line of the manual exchanges given are low if ancilliary lamps are used.

If we compare the Standard British common battery telephone instrument with that used by the Automatic Electric Company, the latter will, probably, be found cheaper, but that would be comparing things very different. The woodwork of the former is much more elaborate, and in the latter there is no induction coil, an electromagnetic receiver being used in series with the microphone. The dial switch is of a very simple yet efficient form.

The transmission efficiency of the two instruments is at least equal, and on a system using entirely the Automatic Company's circuit the latter would probably be found more efficient.

It will be noticed that the increased cost of automatic equipment is more than counterbalanced by the reduction in cost of building, the cubic space necessary being only half of that required for a manual equipment. The cost of a fireproof building, as given, is very low, 0·9 cent per cubic foot, but an automatic building need not be so ornate as a manual and need not occupy such a valuable site.

The manual system is seen at its worst when sub-division takes place. Owing to the cost of line equipment it is not economical practice to concentrate all lines on one large central exchange, even when this could cope with the requirements of a town. It is usually advisable, therefore, to have district exchanges, and the schedule shows the results when 10,000 lines are divided between two 4,000-line and two 1,000-line exchanges. The number of operators necessary is greatly increased. Owing to junction work the A operators' load is reduced from say, 240 calls per busy hour to 115. B operators have to be introduced for work between exchanges, and the total operators will be increased from about 90 to 140. The cost of buildings will also be much greater. The automatic equipment will not be increased seriously, the cost for power plant will be greater, the cost of buildings will not be so serious as with the manual. But with the automatic the efficiency will remain the same as if concentrated in one building, whilst in the manual the service will be appreciably slower, and the liability to wrong connection much greater owing to the repetition of numbers, etc.

It is a very difficult matter to deal with the saving effected in conduits and cable for lines, unless a particular town be laid out for each system; but, generally, I think, it must be conceded that as the service remains always at 100 per cent. efficiency, no matter how the units are distributed, there must be a great saving owing to the possible reduction of the average length of the subscribers' lines, the reduced number of junction lines owing to their greater carrying capacity

under automatic conditions, and to the greater flexibility due to the feasibility of opening an automatic exchange owing to the growing telephonic density of a district, whereas a manual exchange could only be opened at the cost of reducing the efficiency and increasing the operating cost of the whole area.

The cost of buildings is very much less on an automatic system as the equipment is much more compact—no kitchen, rest-room, and other conveniences for operators are necessary. The furnishings, decorations, electric light fittings, are much simpler.

Maintenance.—All operators' expenses are saved except such as are required for trunk service, information desks, and the like. Against this, of course, has to be placed the cost of electricians or mechanics. One

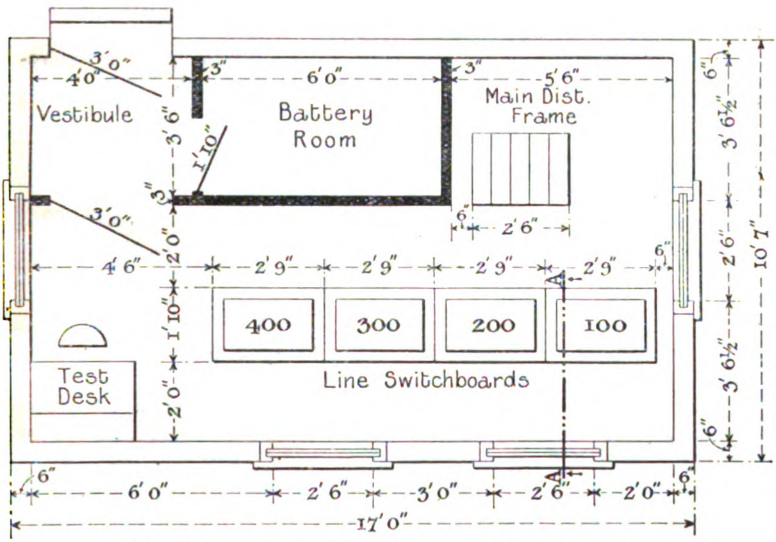


FIG. 20.—Floor Plan of Building to House District Station of 400 Lines.

good man is usually provided for every one thousand lines. Many of the sub-exchanges have no regular attendant, all lines being tested from the nearest main office, and charging of accumulators being over wires from the main exchange, periodical visits only being paid to see that all is in order. Fig. 20 is a plan showing the general arrangement of one of these buildings. The renewable parts are very few, practically only the wipers wear out after many years' use. In the manual exchanges cords and plugs are a serious annual charge, lamps burn out, and answering jacks may have to be renewed.

The Automatic Electric Company have lately published a certificate over the signature of the President of the Citizens Telephone Company, Grand Rapids, that the cost of replacing parts, due to defective workmanship, or material, or ordinary wear and tear, during seven years,

amounted to \$962·62, an average of \$137·52 per annum, or 1·8 cents per line per annum, for the average of 7,500 lines in service. This sum included all central equipment, except power plant, and also the dial switches in the telephones.

Similar data for manual equipments are not readily available. From figures obtained in connection with the Chicago manual system the average cost of repairs on central equipments and instruments is about 27s. per line per annum, the cost of repairs on exchange equipment alone averaging about 17s., the figures ranging between \$1 and \$10, depending on whether the lines were quiet or busy ones. For Seattle the figures are given as 10s. per line per annum, line and exchange equipment, and 10s. per subscriber's instrument. It would be interesting to hear what the costs of repairs are in this country, and further figures regarding automatic equipments.

Semi-automatic systems have been suggested as meeting the requirements of future development, but it is very doubtful if they can be made an economical success. In a proposition put before the last Paris Congress of Government Engineers, a system was described in which the operating, so far as the subscriber is concerned, remains as at present, but in which the A or answering operators have calling devices by which the B or connecting operator is eliminated. This has already been done by the "Clement Auto-manual" system, and is quite workable, and great claims are made for rapidity of service. The only advantage seemed to be that the repetition to the second operator is omitted. The calling subscriber may still send in his call slowly and nearly inarticulately; the operator has to spell out each number wanted by keys or dial.

Semi-automatics seem to me to be good only as a transition measure. The "Traffic Distributor" system of the Automatic Electric Company meets the requirements in an efficient manner. In this the multiple of a manual exchange is retained, but the answering jacks, calling lamps, line and cut-off relays, and intermediate distributing frame are omitted. The keyboard equipment is simplified in that, instead of double cords, only as many single cords are provided as the operator can attend to. From the main frame, lines in parallel to the multiple, are carried to Keith primary line switches with their 10 per cent. of lines to secondary line switches, so that the number of lines is reduced until they are just sufficient to carry the traffic (in the manner already described for junction working). These lines are then distributed among as many operators as are necessary to cope efficiently with the work, the lines ending on the single cords already mentioned. Switching devices are introduced, so that position after position may be thrown out of use, and the work therefore concentrated so that it can be dealt with in the most economical and efficient manner.

It is to be noted particularly that the calls are distributed in rotation to the different operators, so that all have an equal amount of work to perform.

The instruments at the sub-stations are exactly the manual common battery instrument, and the subscriber calls by lifting the receiver. Immediately the line switches act one after the other and extend the line to the plug and the lamp associated with the plug glows. (Meantime the master switch has moved all lines of a group to the next spare circuit to the next operator so that the line is pre-selected.) The operator pulls over the speaking key to answer, lifts the plug, tests and completes the connection in the usual manner.

Time does not permit of the subject of automatic telephony being dealt with exhaustively. The Lorimer, the American Automatic Company's, and other systems would require another paper to deal adequately with them. That there is a great future before automatic telephony I am convinced, and my paper can only be looked on as preparing the way for more detailed consideration of the subject.

References to articles to which the author is indebted :—

Campbell, W. L., "A Study of Multi-Office Automatic Switchboard Telephone Systems." *Transactions of the American Institute of Electrical Engineers*, vol. 27, pt. i., p. 503, 1908.

Truby, F. J., "Automatic Telephony."

Campbell, W. L., "The Multi-Office Automatic Telephone System as applied to existing Manual Plants."

Campbell, W. L., "Modern Automatic Telephone Apparatus." *Proceedings of the American Institute of Electrical Engineers*, vol. 25, p. 165, 1910.

Smith, Arthur Bessey, "Telephone Engineering around the Golden Gate." *Proceedings of the American Institute of Electrical Engineers*, vol. 25, p. 931, 1910.

The Automatic Electric Company's publications.

Discussion.

Mr. J. E. Kingsbury: Mr. Aitken's paper deals not only with complicated details, but with some general principles. It is not my intention, even if I were able, to follow Mr. Aitken into the details, but I would like to be allowed to say a few words on the general principles. First, with regard to the title of the paper. In a case in the Law Courts which was proceeding a few days ago—of some interest to some of our friends personally and of academic interest to us all—the Attorney-General drew a distinction between two systems in practical use in London: one he described as the magneto system, and the other as the automatic system. Was the Attorney-General referring to what Mr. Aitken has been describing to-night as the automatic system? No. The system to which the Attorney-General referred has been described by Mr. Aitken as the manual system. That illustrates, I think, two things. In the first place we ought to find some method of describing apparatus which would make it impossible for two people to describe the same thing by exactly opposite names. It also leads one to suggest that there must be something lacking in Mr. Kingsbury.

Mr. Kingsbury.

one or other description, and I think it will be found in the fact that the Attorney-General was not speaking from his brief, but was speaking from his experiences in the practical use of the telephone, and the ease with which he could operate a common battery system suggested to his mind that it was automatic. In other words, he was speaking from the subscribers' standpoint. Mr. Aitken is speaking from the standpoint of the central exchange, and describes a system of automatic switching which requires a more elaborate operation on the part of the subscriber than that of the present system in general use. I suggest, therefore, that some means should be adopted of standardising the names, so that they would more clearly describe what is intended, and I would say, merely as a suggestion, that what is now termed automatic switching should be called machine switching, that what is called automatic calling should be termed machine calling, and that what is called the full automatic should be described as machine calling and machine switching. That would serve to differentiate three different types: full automatic, semi-automatic, and so-called full manual. I do not think the time has yet arrived when the respective merits of those three systems can be touched upon, and if I have a fault to find with Mr. Aitken, it is his dogmatism in defining the extent to which all or any may be used. He has, however, committed himself, if I may use the term, as a "whole-hogger." He is for the full automatic, and does not believe that anything else can be other than transitory. It may be that he is right. I am not going to say as an expression of opinion that he is wrong. I do not think anybody would be justified in doing so. I would only say that the material is not yet before us which will permit Mr. Aitken to put that forward as an accomplished fact based upon statistical information, or that it would be competent for anybody to say that Mr. Aitken is not a true prophet. We have, however, to bear in mind that either the installation of a telephone system or the modification of a telephone system is a work of considerable cost and extreme gravity; that it is not only an engineering problem of the complexity of which we have all had some idea by the diagrams on the board, but that it is a complex engineering problem mixed up with a complex social problem. Mr. Aitken says in effect that he is a champion of the public; that the public as a telephone caller is really much more of a sensible individual than some other telephone men think. Mr. Carty, who read a paper on this general subject some short time ago, indicated that telephone engineers must be careful that they were not led away by the enthusiasm of the inventor or the manufacturer. Now Mr. Aitken has turned the tables on the telephone engineer, and as a manufacturer says that it is only enthusiasts who hold that the public is incapable of operating a telephone calling machine. I do not hold a brief either way, but I do remember that the telephone is an instrument which permits the transmission of speech; that in the communication of information from one to another the most effective means of communicating that intelligence which nature has provided

Mr. Kingsbury.

us with, is speech. The question is, which does it come most natural to a subscriber to do, to say by words what he wants, or to operate a machine to indicate the same thing? Mr. Aitken dwells on the fact that the telephone in transmitting the intelligence to the operator is indistinct, or may be indistinct, that the call may be indistinct. So may the telephone in conversation be indistinct; but surely if a telephone is worth paying to transmit a conversation which may be of great importance, it also ought to be able to transmit the number which a subscriber requires. That it does not do so always we know. Would the subscriber always be sure of sending by machinery the right number? It may be that he would. I do not wish to depreciate the subscriber's intelligence, although I recognise a difference between sending a machine call on the telephone and operating an automatic machine for a pennyworth of chocolate. There is a difference, but the extent to which reliance can be placed is a matter of experience and statistics. Until we have experience and statistics to guide us it is unwise, it is an unsound engineering practice, to assume that something which has not been sufficiently demonstrated may be relied upon.

Now there is one other point that I would like to refer to, which is the remark of Mr. Aitken's as to the improvement which would be effected by the responsibility of any error in switching being placed upon the subscriber. I have heard that argument before, and I have heard methods of operating telephone systems recommended on that account. Before this Institution I have condemned the proposals which have been made for that purpose, and I hope I shall not be considered egotistical if I say that experience has borne out my objections. I would enter a protest now on the same ground; a telephone system does not benefit anything if it works improperly because it is the subscriber's fault. I would urge that it is the principle, and it should be the governing principle, of those who are responsible for a telephone service to select a method of operation which may be the best for the majority, to take care that the service is a sound one, a perfect one; and not to seek to evade responsibility themselves by putting it on the subscriber.

Communicated: From experience we know that some methods of calling ill adapted to use by the public are of great value when used by experts—for example, the "call-wire" of the law system as a publicly used method is dead, but it still lives as the "order-wire" used exclusively by operators. Experience has also demonstrated that reliability in service is largely increased by simplicity in the construction and operation of the subscriber's apparatus. The introduction of machine-calling apparatus at the subscribers' station reverses the prevailing tendency in development and places there a machine whose operation is dependent upon the maintenance in a condition for work of a series of springs, wheels, and contact-making devices. By reason of the work required of it machine-calling apparatus can never be so simple, and therefore so reliable or economical in first cost as the

Mr. Kingsbury.

existing C.B. type which, replacing a more complex generator, has only to change a contact in order to send a call, the rest of the work being done by a centralised battery and by word of mouth. In view of the enormous growth of telephonic switching it would seem that the application of machinery for eliminating or reducing the manual operations in an exchange would be in accord with the general law of the application of machinery and should offer a hopeful field for enterprise. Complex mechanism would not, in such case, be at the extremity of the line but centralised at the exchange; it would not be put in operation by the unskilled but by the trained hand. Such an arrangement would seem to offer the best chance for reliability and economy, for it must be remembered that the claims made for general economy in the operation of machine-calling and switching mechanisms ("full automatic") omit entirely the subscribers' time element. Further experience may show that machinery can be made sufficiently reliable; that the subscribers are able and willing to do the work requirèd of them; and that all this is economical in working, but until such experience is obtained the application of machinery to machine-switching ("semi-automatic") would seem to be the line of least resistance in "automatic" development, since the change would be entirely of an internal character and maintain the existing conditions for the subscriber which are ideal so far as regards the employment of his time or the application of his intelligence. In expressing these views I do not wish to convey the impression that I consider any limit should be placed to the possible developments in the employment of machinery. Practical tests under working conditions in carefully selected areas should be encouraged with a view to obtaining by experience the definite information now lacking on some very important points. Experiments on the large scale resulting in disappointment would not only be very costly but would also tend to retard real progress.

Mr. Gill.

Mr. F. Gill: Owing to pressure of work I have not been able fully to study the paper. I think I must disclaim credit for the suggestion Mr. Aitken gave to me. I think something I said must have got slightly misunderstood, because the National Company has felt that the function of the private branch exchange operator is very important indeed to the service. We hardly think you can get rid of her by any automatic gear, no matter how it works, for this reason: she has certain functions which demand an intelligence that you cannot get rid of by the substitution of automatic gear. Calls coming into the subscriber's office have to be filtered and the correct representative found. Callers for Mr. Smith want to know what department Mr. Smith is in. Calls going out in the other direction have to be nursed through, and the expensive time of the principal saved by the less expensive time of the operator. Therefore we think that in considering the clearing signal of the private branch exchange it is better practice always to give that signal to the private branch exchange operator, not to the central, and put the control of the supervisory signal in the hands of the private branch exchange operator. It is true some subscribers

do not furnish good attention at their private branch exchanges, but that makes no difference to the principle I refer to. On page 676 there is a large diagram which contains a point Mr. Aitken might explain. All down that 10,000-line exchange the lines to the secondary line switches are on a 10 per cent. basis. I think that is only illustrative. He will put me right if I am wrong. Obviously those subscribers may have different calling rates, therefore the number of lines—*i.e*, 100, appropriate to, say, the subscribers between 0 and 999 may not be appropriate from 2,000 to 2,999. I think that is only my reading of the diagram; the paper is a valuable one, and it might be as well to get that straight. On page 677 there is the same point. He refers to a 10 per cent. basis for junction lines. On the next page (page 678), 22½ calls per junction for a busy hour is referred to. Those are American figures, and it seems to me it would be unsafe for anybody to transplant those figures into this country until he is sure they apply. In London the figures would not apply, the duration of the conversation itself is very much longer than indicated by those figures. Another point I would mention is that he referred to the fact that all special services would be given by the automatic. "All special services" is rather a large order. In the National Company, for instance, the codes which give the operator the indication of the services, and the way to handle them, run up to 60 in number: that is to say, there are 60 different instructions to be given the operator with regard to the way different services have to be handled, and I think in all telephone systems, in all exchanges, there is a survival of old rates, and things like that, which do not clear out very quickly. It is necessary to have different rates and services for different conditions of the public: Mr. Aitken gives that old figure of one man per 1,000 lines. Let us dispose of this once and for all. The last time I came across this man was in the United States, at Los Angeles I think, and I thought I would run him to earth. I went into the thing. One man per 1,000 lines was all right, but I said, "How long does he work?" "Eight hours per day," and I found it was three men per 1,000 lines, with an 8-hours' shift each. I want to know how many men are on the pay-roll, whether it is one man per 1,000 lines, or three men per 1,000 lines. Mr. Gill.

Mr. Kingsbury has referred to the paper by Mr. Carty, and Mr. Carty, I think, gave this very useful caution in this matter. Do not let us call it "manual" *versus* "automatic": that is not the real question; it is rather, Where shall we use "automatic"? In many ordinary forms of telephony there are trains of automatic gear set in motion by the operator or subscriber, and when these are all added up there is really a great deal. The question is not so much whether we shall use an automatic gear, but where we shall use it. Mr. Aitken said truly that the proper course is to study an area. Everybody can point to all sorts of differences here, there, and elsewhere. The manual system is better here, and the automatic system, using the expression, is better there. The only way to treat the thing is to take large areas. If a small one

Mr. Gill. is taken it may be short-sighted. Take a large area and study it right down to the bottom, after having first decided what kind of service is going to be given, and then I think a conclusion will be arrived at. I do not think a conclusion can be come to on the subject by any discussion of diagrams or partial costs; the whole cost must be taken. While on that subject, in the table of costs which Mr. Aitken gives he does not give any traffic basis. Can he help us upon that? It is obvious that the cost of a building, for instance, would largely depend on the calling rate, and so on. The paper by Mr. Carty is one worth reading by everybody interested in the subject. I do not suggest for a moment that men should take their opinions ready made, even though made by a man of the eminence of Mr. Carty. What he says, however, does put an onus on any one who claims that what I may call the full automatic is the proper system. He takes an area, studies it, and gives the result. Therefore I think it puts a serious onus on any one wishing to prove either that the automatic is, or is not, a proper system to use, of doing practically what he has done, that is, studying the whole thing carefully and getting the overall results.

Mr. Whalley. Mr. A. WHALLEY: I had the pleasure three years ago of looking into about five different systems in the United States, and they filled me, I admit, with astonishment and admiration at the results which had then been accomplished. There is evidence sufficient in Mr. Aitken's paper to show that the subject cannot be ignored, and that it is time for the business man, the man in the street, to be consulted. If a system has been evolved after somewhere between ten and fifteen years' hard work, in the face of the keenest competition from the manual system, and in connection with which 300,000 telephones are at work, there must be something in it. The interest of the man in the street is this, I take it, to save his time or money. In this, the largest city in the world, in each working day of roughly five hours, several million pounds sterling must be earned, and therefore each second of time in the working hours must be worth somewhere between £100 and £500. It is claimed by the advocates of the automatic system—Mr. Kingsbury will pardon the retention of the term, as it was first applied to such systems, I should think, nearly ten years ago—or the manufacturers of those systems, that one saving to the public is that the disconnection of the exchange lines is practically instantaneous; it can scarcely be counted in seconds. The bulk of the conversations in London it is known generally by telephone engineers, although perhaps not by the general public, is carried through several exchanges, perhaps three or four, at each of which there is a manual operator, each of whom must observe and be free to attend to the signal to make the proper disconnection. The manual operator who received the call is provided, as a rule, with 17 pairs of cords, and has to attend to anywhere between 100 and 200 subscribers who are sending calls requiring connection, and at the same time, from those who are already connected, she is receiving signals demanding instant disconnection, and the poor soul cannot attend to all at once. The result is that in this most important city

Mr. Whalley.

in the world as regards population, we wait longer than we ought to for our exchange lines to be disconnected. It is said also by certain of the advocates of the automatic system that it takes less time, on the average of all the calls made by subscribers, to get through than on the manual system. All we do know, we people who are users of the telephone exchanges, as we have them in this city, is that the service is very far from being as quick for the purpose of the public as it is with identically the same apparatus in the City of New York. There may be special reasons for this, but the man in the street is not interested in them. He wants to save his money. We have produced in this country telephone engineers who for the most part, both in the employ of the National Telephone Company and of the Post Office, have been brought up in the catechism of the standard American practice, that of the American Telegraph and Telephone Company. The immense sums of money spent by that Company, and the vast experience their engineers have acquired, have meant that our engineers had to go to them to learn. It has been admittedly unavoidable, but the tendency has been for a kind of tutelage to be established, and if any new system that is brought out has not been approved by these, their godfathers and godmothers, for us to be prevented from trying it perhaps as fast as we should if our opportunities had allowed us to develop on our own lines. But I think that the whole matter is one for the man in the street, the business man, and it is a subject that should not be played with. For about ten years all new London telephone exchanges have been of the American Telegraph and Telephone Company's manual type, and the service is not quick enough. If there is any intention of quickening up, improving, and saving the time of the business community, a serious effort ought to be made to investigate this to the extent, not of sending an engineer every year or two to look into it briefly and make a report, but for some one to go and stay in those cities where these automatic exchanges are in use, comparing them from day to day with the manual practice, and, even although the cost should be double in maintenance, if there should be a saving of time to the business man, to let us have a 10,000-line exchange laid down.

Communicated: If we were told that the value of subscribers' time wasted is £1,000,000 per annum we might be surprised. But it may be short of the mark. For 100,000 subscribers it means £10 per year each, yet then so small a sum as 8d. per working day, or 1d. per call at an average of 8 per day. If the time wasted is one minute, then the average value of a subscribers' time is 5s. per hour; if half a minute, 10s. per hour, and so on. If there are 500,000 subscribers, the loss at the same rate is £5,000,000, and if the loss per call should be 4d., then £20,000,000 *per annum* for the same number. Whatever the correct value of subscribers' time lost, it is a serious figure; an annual loss, and more than loss. When money is lost or stolen, it may possibly be regained, and usually is not destroyed, but is available for circulation. Time lost is destroyed. The

Mr. Whalley. total capital sunk in telephone exchanges in this country is under £30,000,000. Who can put a limit to the capital value of the time of the business community? What is the time per conversation likely to be saved by the automatic system? The average time the junction lines in a particular town, equipped with a manual system, were in use for a conversation was found, as the result of thousands of tests, to be 2 minutes. The automatic system, with the same subscribers, brought this down to 1·33 minutes, a saving of two-thirds of a minute. Also the maximum number of lines engaged at any time fell from 14 to 8 per cent., reducing by nearly 50 per cent. the chance of a subscriber finding the line he wanted was engaged. It appears reasonably certain, therefore, that a large fraction of one minute would be saved.

Mr. Conner. Mr. M. S. CONNER: In order to follow the paper I believe it will be as well to consider that the automatic system is the system that is described by Mr. Aitken, and the Manual system is the system that we regularly understand as the manual system. Before going deeply into the matter, however, it would appear to be wise to analyse just what the automatic system so-called consists of. It would appear that it consists of doing a certain number of things automatically and a certain number of things by machines under the control of the subscriber. I believe that all of the things that it really does automatically with the exception of the automatic instantaneous disconnect or taking-down of the connection are found in the manual equipment. The automatic ringing of subscribers, the automatic registering of calls, the ringing of party lines without the resource of special party line ringing keys by connecting each subscriber to a different jack are well known in the manual field. I believe also some of the advantages Mr. Aitken has brought out of reducing the number of junction lines between the exchanges are, more or less, the result of the decimal system of junctions which seemed to appear almost automatically with the automatic system, and of getting rid of those superfluous junctions which were not needed by the service required. It would seem therefore that we have only to compare the making of connections by machines with the making of connections by operators. I feel, after having made a very extensive investigation of the matter at one time, that, contrary to usual opinion, the automatic system so-called, is a successful system for giving telephone service. The subscribers like it, and I say this after having interviewed hundreds of them in various places. The service is quick, and I believe therefore that we are really reduced to considering the question from a financial point of view. If we take the figures of a representative telephone-operating organisation, we find that the expense of operators is very rarely more than one-quarter of the total expenses, and under good organisation it should only be one-fifth, even though the system may reach to 30,000 or 40,000 lines. With such figures we evidently have not very far to go to make up a corresponding amount for expenses and, proof to the contrary notwithstanding, it would seem that this is made up in

automatic systems in cost of maintenance and depreciations. It is hardly possible to read through the five pages in Mr. Aitken's paper which describe the putting through of a connection by the automatic system without realising the enormous number of contacts that have to be made and broken before the connection is established, and if we believe that the cost of maintenance of a piece of mechanism is purely a function of the number of operating parts, we must realise that the cost of maintenance of automatic systems is more than the cost of the maintenance of manual systems. As far as the subscribers' instruments are concerned, under ordinary conditions they should be identical with the exception of the rotary switch. We have no right to compare the latest form of telephone that may be used with an automatic system with an older type of telephone that may be used with the manual system, and it hardly seems right as is suggested in Mr. Aitken's paper, that the maintenance of the subscribers' instruments may be anything from 1 dollar to 10 dollars, whereas the maintenance of the automatic system all through is less than 2 cents per station. I am certain the amount of derangement of the automatic apparatus is greater, and I do not believe that I can illustrate the matter more forcibly than to state that about four years ago I made a visit to the automatic exchange at Columbus, Ohio. It was late in the afternoon between four and five o'clock, and I saw four or five trouble clerks taking down complaints as fast as they could answer the calls. The next day I went to St. Louis, and at 11 o'clock in the morning, the busiest hour of the day at a central battery manual exchange that had more subscribers connected than the Columbus exchange, there was one employee sitting at the clerk's desk reading the morning paper. I do not think that Mr. Aitken's deductions concerning the cost of buildings are well founded. Operators are employed to some extent in automatic exchanges and therefore accommodation must be found for them. I do not see that there is any reason for having more elaborate premises merely because there are more operators. We get a great many comparative statements which always turn out to be studies. I have never been able to find them yet substantiated by audited figures. From the large number of automatic exchanges which are in operation the available audited balance sheets of the companies operating these exchanges do not show greater earning power than those of other companies operating manual systems. Some of these balance sheets do show rather small expenses, but we see exceedingly large additions to capital, and the capital value of each station mounts up each year. This is not healthy. It is therefore very evident to me, and should be to any one who carefully investigates the matter, that up to the present time no automatic system or machine-operating system has been devised that can give a good reliable telephone service at the same expense at which a corresponding service can be given by modern manual equipment. I believe that the question of depreciation also has a bearing on this matter. Mr. Aitken has given in the table in his paper that a manual switchboard has a life of 10 years. There are a

Mr. Conner.

Mr. Conner. large number of common battery switchboards in existence to-day that have been in existence for more than 15 years. The Bristol exchange of the National Telephone Company has been in operation nearly 11 years, and I am certain has many years of service before it. I further believe that the Postmaster-General is expected soon to acquire a large number of telephone exchanges which have been in operation more than 10 years. With the recent improvements that have been made in the choice of material for the making of springs and jacks and the proper shape of plugs, the life of these articles which most rapidly wear out has been greatly prolonged, and I do not think I am going wrong in stating that it is not difficult to-day to get a multiple switchboard that will be in good operating condition, aside from the necessary replacement of plugs and cords, in 25 years. On the other hand, we have had no experience of the automatic system for any great length of time. The systems that were installed 14 or 15 years ago have passed away a long time since. The switch mechanism consisting of the vertical and rotary motion of the vertical shaft of the selector and of the connector does not go through a cycle of operations, and any wear that may take place in this part cannot be taken care of by adjustment. It is evident that the first step on both of these motions is used every time the switch is used. The second step is not always used, and so the first step must get a great many more times wear than the last step; when this wear is enough to throw the wipers out of adjustment the switch jams and the vertical shaft must be replaced. It is a fact that large quantities of them have had to be replaced in a very short time. I believe that there may be hopes for automatic telephony if by some improvement or invention a very large proportion of the number of parts required to make up the mechanism can be done away with. The apparatus could then be made in a more robust and scientific manner without costing too much, and could be protected from dust and otherwise approach the quality of the apparatus that is used on manual equipments. If this could be done the maintenance, of course, would decrease, but when we consider that the Strowger patents were taken out in 1888 and that during 25 years enormous sums of money have been expended in bringing this device to perfection, which has resulted not in simplification but in more complications to correct defects, we get rather discouraged as to any advantageous use of it. With reference to the question of semi-automatics I should rather be inclined to agree with Mr. Aitken. Why we should have in the exchange all the connecting apparatus and the operators as well I do not understand. The semi-automatic, therefore, would appear to have the disadvantage of both of the systems and the advantages of neither of them.

Mr. Scruby. Mr. R. SCRUBY: My remarks will apply to the Automatic Electric Company's system, as that is the only entirely automatic system which has had a really good test, and stood up to that test. I should like to know if any change has been made in the party-line instrument since the one first designed, as I believe the first party-line instruments were

installed at Allentown, Pennsylvania. From the tests I made they did not work as satisfactory as one would wish, and I believe a great number of these instruments were taken out. Regarding the operation of the manual, as compared with the automatic switchboards, although I do not forget the operators of the Allmänna Exchange in Stockholm, whose dexterity was wonderful considering the apparatus they had, nor the operators at the China Town Exchange in San Francisco before the fire, who were not girls who would leave before they attained any great efficiency, but Chinamen. Remembering, as I say, these cases in which there exists a very high operating efficiency and operators who will be content to stay, yet I am sure the automatic is the best system in the end. About seven years ago I went to Albuquerque, New Mexico, to see one of the first automatic telephone exchanges which had been put in. This was of about 200 lines, and had been working six years; it was giving entire satisfaction to the users, and was a financial success. At Grand Rapids a 10,000-line exchange was installed, and was giving thorough satisfaction to the subscribers; it was also paying good dividends before the advent of the Keith line-switch and the common battery two-metallic-line instruments. The Keith line-switch opens up greater possibilities, and allows much greater economy in the automatic telephone system, and I am sure that the system in Chicago will show that there is practically no limit to the number of lines which can be used on the automatic telephone exchange system, although this Chicago system has been installed under such rushed conditions. About eight years ago I was in Los Angeles to see what then was the finest independent manual exchange in the United States. The service given was excellent; only a year or two after that date all extensions to this system were not manual but automatic, and now they have one of the largest automatic exchanges in the world. Having lived for three years in Dayton, Ohio, where there was a manual exchange and a 10,000-line automatic exchange, I can assure you that the public were very much in favour of the automatic exchange. I had an automatic instrument in the house where I lived, and I cannot remember ever getting a wrong connection, although I used the instrument to a considerable extent. Mr. Scruby.

The telephone service engineers in considering the feasibility of automatic telephone exchanges bring up these two points: the first cost of the apparatus, and maintenance. Mr. Aitken says there are already 300,000 instruments in use. Although this is surely ample to show the reliability of the service, from a manufacturing point of view 300,000 is not a very great quantity of telephones to get a very low manufacturing cost and a design which will bring the maintenance to a minimum. The automatic telephone system is largely a manufacturing problem; only one firm has, up to now, been making the apparatus, and the repetition orders are not put through the factory in anything like the quantities which they are in some of the manual telephone works; consequently, when more manufacturers produce automatic telephone apparatus, and repetition orders are placed on a scale of the

Mr. Scruby. manual orders at the present time, we may expect considerable reduction in the cost of the automatic apparatus; in fact, the manufacturing cost of the automatic apparatus must now drop quicker than the manual. I should like to mention that in the whole of the automatic telephone system there is not one part upon which so much scrap is made in manufacture as the 3-point C.B. plug and multiple jack, but this is not the only saving the manufacturer can make. As the quantities manufactured increase, the maintenance of such a complex piece of apparatus is brought down considerably; for example, the manufacturer designs such testing apparatus as will automatically give the apparatus a lifetime test before it leaves the works. Such testing is given to a cash register, for instance, which is a much more intricate piece of apparatus than an automatic telephone, with the result that maintenance is almost negligible. Furthermore, although England, as compared with the United States, is not manufacturing an enormous number of telephones, nevertheless there are one or two telephone manufacturing companies in England that are turning out better work than any of the foreign works, and these will be a considerable help to the English telephone system when they decide to commit themselves to automatic telephony. I should like to emphasise the necessity of having a cosmopolitan telephone. A man in a foreign country generally wants to telephone to some one speaking his own language, therefore a cosmopolitan calling device is a great help. I know that in Stockholm I had the greatest difficulty in getting people on the telephone. It was no fault of the operator or system, as a manual system. The service was excellent; it was my atrocious Swedish. If the automatic had been installed I should have used the telephone much more often, as everybody I wanted to talk to could speak English.

Mr. Kennedy. Mr. D. H. KENNEDY: I should like to say a few words on the subject of nomenclature, which has been referred to once or twice. I would submit that the system which has been described by Mr. Aitken is a system which is better described by using two words than one. It is an automatic switching system. The systems at present in existence in this country have, I think, been divided for statistical purposes into two. They are both manual switching systems and have been described as the non-automatic signalling system, meaning the magneto system and the automatic signalling system, which refers to the central battery system. Several times during the past week I have heard the Attorney-General referring to the central battery system, and so far as my recollection goes he was careful to use the second word as well as the first, always calling it the automatic signalling system.

Mr. Holme. Mr. T. HOLME (*communicated*): I think the author has made out his case in favour of the automatic for large multi-office schemes, as the elimination of B as well as A operators, and the economies in junctions would materially affect the rental to be charged for the service. For so-called single office systems it is very problematical indeed whether any business concern would go in for so complete a change on the

doubtful assumption of a saving of 17 shillings per line. The comparative costs given on page 687 are very interesting, but need revision from a British cost point of view. I may say we have a 10-line automatic exchange in connection with the service at Hull in a village about 6 miles from the central exchange. It is a very small affair, but it may be of interest, as I believe it is the first exchange of its kind to give public service. It consists of the usual rotary and release mechanisms with a busy-back circuit, which is only set up when an engaged line is tried, and is worked by a couple of dry cells. The subscribers' instruments are fitted with hand generators, and they ring through after setting up a number. The capital cost runs out at £4 per subscriber for the exchange apparatus and £2 10s. for the instruments. The system has been working just a year, and the maintenance cost for that time has been extremely low. Mr. Holme.

Mr. A. L. STANTON (*communicated*): As it has been my experience to have had facilities for observing some phases of automatic equipment in actual operation, the paper contains much matter of interest. I therefore wish to offer a few remarks. To telephone men the subject of full automatic equipment is becoming of increasing importance, as will be at once obvious when such questions as the elimination of operating expenses, the reduction of office cost and attendant charges come within the range of practical accomplishment. Existing conditions here are such that certain efforts tending towards the production of definite standards of equipment and line design are in force, but in this respect the telephone business bristles with difficulties, as manufacturers in particular will be well aware of. The standards aimed at in present practice are based upon features essentially the outcome of the highest types of manual service, wherein the efficiency is extremely high: for the human element functions are reduced to a minimum, the actual operations largely include automatic principles, and, apart from commercial limits, a uniformity of transmission is obtained difficult to excel; it may also be safely stated that very few areas exist in Great Britain where evidence of capital charges in the shape of manual service plant in place is not to be found. Perusal of Mr. Aitken's paper leads us to suspect that under the present conditions the cost of installing single exchange equipments under 10,000 lines works out with a considerable credit on the side of manual when such service *versus* full automatic is in question; therefore accurate information on this point applicable to conditions over here would be of value. I do not think it will be incorrect to state that a very large proportion of the telephones throughout the country are connected to single exchanges coming under this category, and, unless the optimism of the Postmaster-General is justified, some time will elapse prior to the demand for many exchange equipments approaching 10,000-line service values. The gradual conversion of service from older to more modern types has also been possible along lines which at certain stages of development have spelt less initial outlay and loss on original value of plant in place than would apparently be Mr. Stanton.

Mr. Stanton.

the case where conversion to full automatic working takes place; moreover, my experience is that the admittedly complex questions involved by efficient intercommunication and distribution do not, at least in provincial areas, admit of consideration along American lines. Statistics covering the all-important question of annual maintenance costs are also highly desirable; my observations are that the staffs engaged on such equipment necessarily must be trained to cope with duties demanding a higher order of average ability than is now to be found available on manual service. If it is not out of place to make the inquiry I think it would be of interest to know what information is available regarding the reliability of adjustments, what effects result from variation in voltage, and what is the minimum permissible insulation value for distribution. The problems to be faced when considering this country as a field of probable development for full automatic equipment are such as would demand very serious attention from a financial point of view. I am of opinion, however, that at no distant date conditions will arise containing the groundwork of full automatic possibilities. Given satisfactory expenditure liabilities, the supply of service to small exchange areas, including private branch exchange requirements, would appear to be suitable for proving the merits of some of the numerous switching arrangements utilised, and no one who is acquainted with what has been accomplished by the engineers engaged in developing such equipment can have any doubts about its capability for ultimately surpassing the best manual service where flexibility is concerned. In practice, however, this factor alone spells an increased complication of mechanism operation, having a tendency to exceed the value limits of advantages derived, since it has a commercial aspect which cannot be ignored. Referring to the author's first statements in connection with private branch exchanges, and without in any way desiring to underrate the value of the improved boards giving automatic disconnection advantages, I think it will be admitted that when the number of extensions on any of the small boards now in general use exceeds a unit figure value, it will be found that a regular attendant becomes a necessity, which the telephone authority supplying service are not backward in pointing out for traffic reasons. It follows that neglect in this direction can only result in unsatisfactory service, seriously augmented if, as is usually the case, a considerable proportion of extension connections are completed through the main exchange by junctions provided for the purpose. Viewing the matter thus, I venture to submit that the percentage of troubles due to main exchange connections being left through to private branch extensions after the clearing signal has been given is a negligible factor when good service essentials are provided. A scheme of automatic working should provide for eliminating the private branch exchange operator altogether to be successful, and my knowledge of the difficulties experienced in connection with the education of subscribers as regards the correct way to handle a telephone does not, I am afraid, produce the optimism the author evinces towards effects directly resultant upon telephone

users who have to control the whole operations essential to the maturing of connections. The average subscriber in Great Britain does not yet appreciate the value of telephone service to anything approaching the extent given in American service. Mr. Stanton.

Mr. W. AITKEN (*in reply*): Various speakers have dealt with the words used to describe the various systems, but I fear those suggested by Mr. Kingsbury are too long, and are not descriptive enough. The terms used have the advantage of being brief and, on the whole, very comprehensive. The system in general use here is manually operated, and, therefore, generally the word "manual" is sufficient to describe it. If one wishes to speak of a particular division, one would add "automatic signalling," or "magneto signalling." In the system I have described the switching or operating is automatic for, say, nine-tenths of the work, and may therefore be fairly described under that heading. Semi-automatic usually describes a system where the operator continues to answer the calls, but in which the remainder of the operations are automatically performed. Mr. Aitken.

Mr. Kingsbury thinks that I have been too dogmatic in defining the extent to which the automatic system may be used; I have simply taken the facts as I found them. I find that several of the largest towns in the United States have adopted this system in a very large way, and, apparently, are perfectly satisfied with it. I think there is sufficient material available on which to base an opinion. The manual system is becoming, if anything, over-elaborated, for example, by the introduction of three calling signals and three answering jacks per subscriber's line, so as to give nine operators facilities for answering a call from a subscriber.

Mr. Kingsbury argues that, if the telephone is good enough to carry on a conversation with, it should be good enough to hand in a call to an operator, but he overlooks the fact that another telephone—namely, the operator's—is brought into use in performing this act, and, whilst the two telephones required for the conversation may be satisfactory, the telephone to the operator may not be so. Mr. Kingsbury also lays stress on the words I used, "that, if an improper connection was made, the subscriber was to blame." Naturally, the apparatus given to the subscriber to use must be such that it will not get out of order readily, and that he is only responsible for sending in wrong calls. It, however, seems to me that the subscriber, after using an instrument a few times, will become quite expert in the use of the dial.

With reference to the small switchboards with automatic disconnecting facilities, I regret the misunderstanding with Mr. Gill. I understood from him that he was in favour of the subscriber, when once connected, being able to pass several messages through to the central exchange without the intervention of the branch operator. On the circuits in general use I know this is not possible, as the holding coil is across the circuit during conversation—a feature, in my opinion, prejudicial to good transmission. These small switchboards, however, can be used with or without the slow-acting relay, as required, and

Mr. Aitken. therefore the entire supervision can be given to the branch operator, or the subscriber allowed to signal the central operator, as desired. These switchboards are specially designed for use in offices, having a small number of extension lines, where no regular attendant is provided, and, where a three or four-line switchboard exists, it is very rarely a special attendant is provided. It is the duty of the office boy, or any one convenient, to make or disconnect a connection. As the call is by bell, if the switch is left in the proper direction, any one can be trusted to make the connection; as, however, the clearing signal is silent, if there is no regular attendant, the connection may be left through much longer than required, to the detriment of the public service, and I think this automatic disconnection facility will be found a great advantage, both to the subscriber and to the central exchange. The holding coil is cut off automatically, and the board is practically fool-proof.

For the reasons specified by Mr. Gill, the Automatic Electric Company do not recommend complete automatic in branch exchanges, because it is found that the special service required at branch exchanges is better carried out by an operator than by the full automatic, although, in practice, it is frequently found that the full automatic is an advantage for certain of the branch lines, and certain lines to be worked manually. The automatic system, however, is so flexible that either all, or part, may be worked automatically or manually, the essential automatic feature being that all the lines to the branch exchange are available to a subscriber who calls the number designating that exchange, the automatic apparatus then selecting the first idle junction line to the switchboard.

If Mr. Gill refers to the large diagram Fig. 12, he will notice that an intermediate distributing frame is introduced between the primary and secondary line switches, on which the traffic may be equalised just as is done on the intermediate distributing frame of the manual system. With reference to the 10 per cent. basis for junction lines (page 677), the apparatus is manufactured on the 10 per cent. basis, but it is not necessary to connect up all the circuits. The circuits connected up will depend entirely upon the traffic, and the introduction of the secondary line switch, in connection with junction working, ensures the reduction of the number of junction lines to the minimum necessary to carry the traffic efficiently. As regards the number of calls per junction line, may not the longer time taken for junction calls in this country be due to the fact that they are manually operated, whereas junction calls automatically operated and automatically disconnected instantaneously make it possible for junction lines to carry a much greater number of calls per busy hour? I agree with Mr. Gill that "all special services" seems a large order, but my brief experience of automatic systems is, that any problem put before automatic experts is invariably solved in a satisfactory manner.

I am sorry I cannot definitely settle the point Mr. Gill raised with regard to the maintenance by one man per 1,000 lines. This is a

Mr. Aitken

figure usually quoted, although I have seen it lately reduced to 700 lines as the average. Certainly it is not three men per 1,000 lines per day. The one man taking 1,000 lines may be right for the busy hours of the day, but during the quieter hours a man looks after several thousands. I expect it depends partly on whether the equipment is a new or old one to some extent, and also on the ability of the man. I am sorry I have not, at the moment available, any traffic data that would be helpful to Mr. Gill. I have been informed, however, that in Los Angeles, the calls per line are exceptionally high, something like 25 calls per line per day.

Mr. Whalley is able to speak from experience of the operations of exchanges in America, and his remarks are very interesting. I think it is only reasonable to expect that there would be a great saving in time and money, if the automatic system were adopted, owing to the rapidity of service subscribers' lines testing less frequently engaged, and the carrying capacity of the lines being increased.

I was pleased to hear Mr. Conner's remarks, particularly that the method of automatic calling was appreciated by the subscriber. This agrees with all I have heard on the subject, and, for this reason, the automatic telephone is used to a greater extent than the manual system. The automatic apparatus looks more complicated than it really is; mechanically the selectors and connectors are very similar. Wearing parts are principally associated with the wipers. Mr. Conner says that the shafts also wear, but in apparatus I have had access to and which has seen a considerable amount of service, there is nothing to indicate this. Mr. Conner says that we have no right to compare the latest form of telephone that may be associated with the automatic system with an older type of manual telephone, but I fear the same argument applies with regard to automatic systems. We are inclined to compare and judge an apparatus that was made a number of years ago. It is to be borne in mind that within the last few years great advance has been made in manufacture and design of automatic equipment. The quality of the metal used for the springs and other parts is of a quality very much higher than is generally used in manual equipment, and other mechanical details have also received very careful consideration. The 2-wire system has introduced both complications and simplifications, and the 2-wire line switch has reduced the number of parts very considerably, and the great feature of the Automatic Electric Company's system—namely, the simplification of the impulse sender, or dial switch—has removed the reproach that was commonly urged against the automatic equipment, that the apparatus at the sub-station was made complicated and expensive to maintain. The automatic exchange of Columbus, quoted by Mr. Conner, is not one of the exchanges on the 2-wire system. I do not think there is any doubt about the simplification of the automatic equipment in the future, although it seems difficult to see how the number of selectors and connectors can be reduced to get a switching system that will deal with hundreds of thousands of lines,

Mr Aitken. but I know that simplifications in other directions may be expected at an early date.

Mr. Scruby's remarks are interesting from the varied experience he has had of different exchanges and systems, and I note he classifies the service from the automatic system as excellent. Mr. Scruby emphasises the necessity for the automatic by specifying the language difficulty. There is no doubt that, in many of our great cities particularly, the automatic telephone would be a great boon to the traveller.

It is, I think unfortunate that Mr. Holme has not informed us as to which type of automatic exchange he uses. One can only assume that it is a Swedish pattern, and it is interesting to note that it gives little trouble.

With reference to Mr. Stanton's remarks that "my paper makes out that the single exchange equipment, under 10,000 lines, works out with a considerable credit on the side of manual," I think Mr. Stanton has misunderstood me. Whilst switchroom equipment costs more than with the automatic, yet, when the whole installation of outside and inside plant and buildings are considered, the automatic system works out very much cheaper, and for exchanges of a very much smaller number of lines than 10,000. With regard to the reliability of adjustments, I do not quite understand what is covered by this, but the apparatus, when properly installed and adjusted, works reliably without the necessity of frequent readjustments. The variation in voltage due to length of line is quite comparable with manual common battery systems—you have simply the battery on the line through the relay coils. All the electromagnets doing the switching are in local circuits. The line insulation resistance necessary is also practically equal to a 40-volt manual common battery system. Mr. Stanton also mentions the small boards with automatic disconnection facilities, but I have dealt with these already. He states that the percentage of trouble due to main exchange connections being left through to private branch exchanges, after the clearing signal has been given, is a negligible factor, when good service essentials are provided. This is readily agreed to. These boards are primarily designed for small installations where, for purposes of economy, an attendant is not provided.

The President. The PRESIDENT: I will now ask you to accord a hearty vote of thanks to Mr. Aitken for his interesting paper.

The resolution of thanks was then put and carried with acclamation.

Proceedings of the Five Hundred and Twenty-fifth Ordinary General Meeting of the Institution of Electrical Engineers, held on Thursday, May 25, 1911—Dr. R. T. Glazebrook, C.B., F.R.S., in the chair.

The minutes of the Ordinary General Meeting, held on May 18, 1911, were taken as read, and confirmed.

The list of Candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Hall.

The following list of transfers was announced as having been approved by the Council :—

TRANSFERS.

From the class of Associate Members to that of Members :—

Arthur Ranulph Bacon.	John Geo. Griffin.
Henry Wm. Clothier.	Alfred Jacques Makower.
John Dennis Coales.	Thomas Plummer.
Edward Winram Dickinson.	Hubert Conrad Sparks.
John Edward Donoghue.	Charles Stewart.
Frank Arnold Greene.	Charles Vernier.

From the class of Associates to that of Members :—

Edmund Algernon Hall.	Reuben Marchant Sayers.

From the class of Associates to that of Associate Members :—

Jack Flinders Caine.	Frank Tracy Hamilton.

From the class of Students to that of Associate Members :—

Alfred Ardern.	Gracchus Brown Dent.
Leonard Cecil Baldwin.	Stanley Dudman.

From the class of Students to that of Associates :—

Gordon Pullman Bailey.	Herbert Geo. Jenkins.

William Henry Whitehouse.

Messrs. M. Rosenbaum and E. L. Webb were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected :—

ELECTIONS.

As Member.

William Edward Robson.

As Associate Members.

Thomas Edwin Alger.
Philip Francis Anley.
Sidney Bates.
Roy Apted Broad.
Lionel George Caunter.
Richard George Devey.
Frederick Johnson Gellion.
Claude Henry Grindrod.
Percy Sydney Hawkins.
Thomas Hayes.
Edward Frederick Johnson.
Christopher Jones.
John Caradoc Jones.
Claud Henry Klyne.
John Lingard.
Frederick Walter Parsons
Harry Pilling.
Robert Dalziel Runcie.
William Travis.
George Pritchard Turner.
Reginald Claude Wallroth.

As Associates.

Walter George Barnett.
William Bell.
Daniel Nicol Dunlop.
William Heap.
Andrew Wilson Tait.

As Students.

Charles Garfield Abbey.
Vivian Otto Haddock.
Lawrence Thomas G. Mansell.

The following paper, "The Heating of Cables with Current," by S. W. Melsom, Associate Member, and H. C. Booth (see page 711), was read and discussed.

THE HEATING OF CABLES WITH CURRENT.

By S. W. MELSOM, Associate Member, and H. C. BOOTH.

(FROM THE NATIONAL PHYSICAL LABORATORY.)

(*Paper received February 9; received in final form April 27. Read before* THE INSTITUTION *May* 25, 1911.)

The object of this paper is to describe an investigation which was made at the National Physical Laboratory by permission of the Executive Committee at the request of the Wiring Rules Committee of the Institution in order to determine the temperature rise and current density for a given temperature rise in cables of various sizes and with different types of covering.

TABLE I.

Type of Covering.	Size of Conductor.			Maximum Current according to I.E.E. Rules, 1907.
	Gauge.	Sectional Area.		
		Square Inches.	Square Millimetres.	
Rubber	1/14	0·00503	3·24	9·8
Rubber	3/18	0·00532	3·43	10·3
Paper	3/18	0·00532	3·43	10·3
Twin paper ...	3/18	0·00532	3·43	10·3
Rubber	7/21	0·00554	3·58	11·0
Rubber	7/18	0·0125	8·05	21·0
Rubber	7/16	0·022	14·2	33·0
Paper	7/16	0·022	14·2	33·0
Concentric paper	7/16	0·022	14·2	33·0
Rubber	19/18	0·0034	21·9	47·0
Rubber	19/17	0·0046	29·7	60·0
Rubber	19/14	0·0094	61	108·0
Rubber	19/0·082	0·100	64	113·0
Paper	19/0·082	0·100	64	113·0
Concentric paper	19/0·082	0·100	64	113·0
Rubber	37/15	0·150	97	157·0
Rubber	37/0·101	0·300	194	280·0
Rubber	61/0·101	0·500	323	425·0
Paper	61/0·101	0·500	323	425·0
Concentric paper	61/0·101	0·500	323	425·0
Paper	91/0·118	1·000	645	750·0

A length of 40 ft. of each of the following sizes of cable, Table I., were tested, the smaller rubber-covered cable being tested when laid under various conditions, such as in wood casing, iron tubing, etc.

Insulation.—The insulation of the cables was of the standard pattern, the paper-insulated ones being lead covered, and the rubber-insulated (with the exception of the 0·3 sq. in., which was only rubber covered and taped), being taped, braided, and compounded.

General Conditions Under which the Tests were Made.

Method of Laying.—The rubber-covered cables marked A on the curves, and the paper-insulated lead-covered cables marked E on the curves, were in each case laid out flat along the wooden floor of the room, the lead and return being close to and touching each other. The concentric paper-insulated lead-covered cables, F_1 on the curves, were laid straight out along the floor, the current being led into the inner and returning by the outer lead.

Rubber Cables in Casing.—In the case of the rubber-covered cables in casing, marked B on the curves, the casing used was in each case twin and of the standard size for the various cables, and was supplied by the Wiring Rules Committee. The casing, however, in some cases allowed of a rather larger air-space than in others. The ideal condition, from the point of view of dissipation of heat, is to have the cable nicely filling the groove.

Table II.

Diameter of Cable.	Total Area of both Cables.	Area of Inside of Tube.
Inch.	Square Inch.	Square Inch.
0·23	0·08	0·33
0·40	0·25	0·60

The casing was laid flat along the floor. Observations made with it screwed to a board and supported on one edge, with the wires one above the other, showed no difference whatever from those made with the casing laid flat and with both wires in the same horizontal plane.

Rubber Cables in Iron Tubes.—The iron tubes used were supplied by the Wiring Rules Committee for the various sizes of cables. In each case both the lead and return cables were drawn into the same tube. The dimensions of the tubes and the size of the cables are given in Table II. It will be seen that there was a considerable amount of air-space inside the tubes which would tend to retard the dissipation of heat, but, in view of the injury to which the insulation is liable while drawing in, it would probably be inadvisable to reduce the size of the tubes.

The cables marked C on the curves were drawn into the iron tubes and laid straight out along the floor. In the case of those marked D and D′ the tube was embedded in a block of plaster running the whole length of the tubes, the plaster being 4 in. deep by 6½ in. wide.

Measurement of Temperature Rise.—The increase of temperature of the cables was determined by measuring the increase of conductor resistance. The air temperature was taken by a number of thermometers placed at the same level as the cable, but about 3 ft. away. The initial temperature of the cable was assumed to be that of the air. Observations taken both on a rising and falling air temperature showed that even the larger cables followed the slow variations of air temperature very well.

The room in which the tests were made was specially adapted for constancy of temperature and was free from any draught. The temperature was very even (the four thermometers placed at various points along the 20-ft. run of cable in no case showed a greater difference of

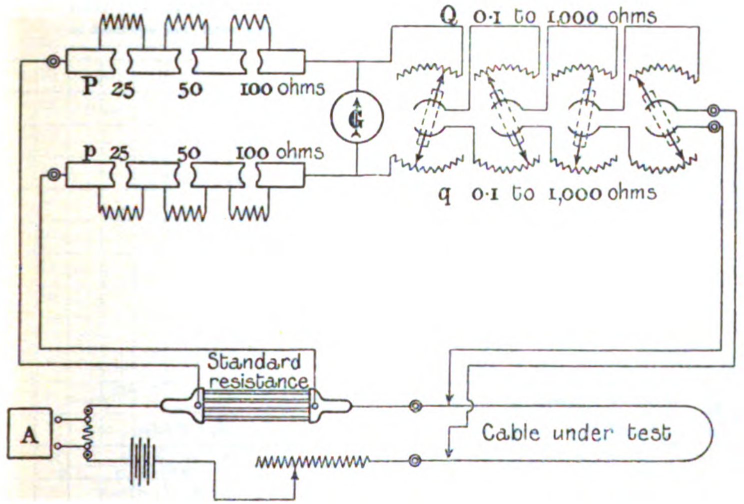


FIG. 1.

temperature than 0·2° C.), and the variations with time were very slow and small. The maximum difference from highest to lowest during 24 hours was 2·5° C., the quickest rate of rise or fall at any time being about 0·3° C. per hour.

The temperature coefficient of the cables was determined over the range of temperature covered by the tests. Lengths of about 1 metre were cut off five of the cables and each of the wires tested separately in an oil bath at various temperatures. The coefficient obtained and used for the determination of the temperature rise is expressed by the formula—

$$R_t = R_{15}\left\{1 + 0{\cdot}0040\,(t - 15)\right\},$$

where R_{15} is the resistance of the conductor at 15° C. and R_t its resistance at $t°$ C.

An interesting point was raised by Mr. Wordingham in connection with this method of determining the temperature rise. It was that there was a possibility of the strands of the larger cables, when hot, coming into better contact than when cold, and that consequently the resistance of the conductor would not rise proportionately with the temperature. This point was investigated by enclosing the 0·5-sq. in. paper-insulated lead-covered cable in a long wooden box, which was heated by means of woven resistances to a temperature of 50° C. The current used to measure the conductor resistance was small and only on

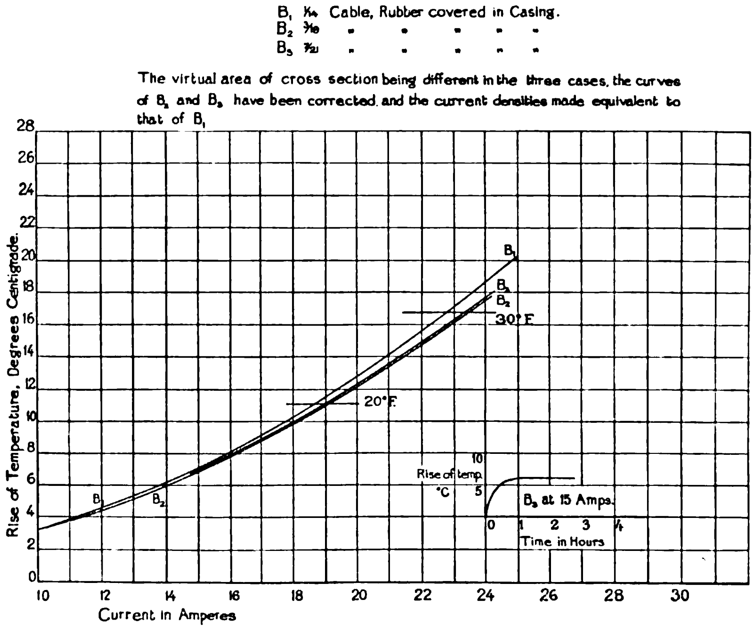


FIG. 2.

momentarily. The mean temperature was taken by a number of thermometers in various parts of the box. The temperature was maintained at a steady state and observations taken at several points up to 50° C. The temperature coefficient of the conductor was found to be 0·396 per cent. per °C. The difference between this figure and that of 0·40 per cent. obtained by the more accurate method of measuring the separate wires in an oil bath is within the limits of errors of observation, and shows plainly that the variation in resistance, if any, due to tightening of the strands, does not affect the accuracy of the results.

The temperature determined throughout the tests is, of course, the mean temperature of the conductor over its cross-section and not the

maximum to which any part may have risen. It was assumed, however, that there was no appreciable error due to any difference of temperature distribution. Dr. A. Russell * has investigated this point, and states that the temperature difference is very small.

Measurement of Conductor Resistance.—The measurements of the resistance of the conductor were made by means of a Kelvin double bridge of the direct-reading pattern made by O. Wolff. The principle of the Kelvin double bridge is well known, and it is probably unnecessary to refer to it further than in the diagram of connections shown in Fig. 1.

3/16 CABLE, NOMINAL CURRENT 10·3 AMPERES

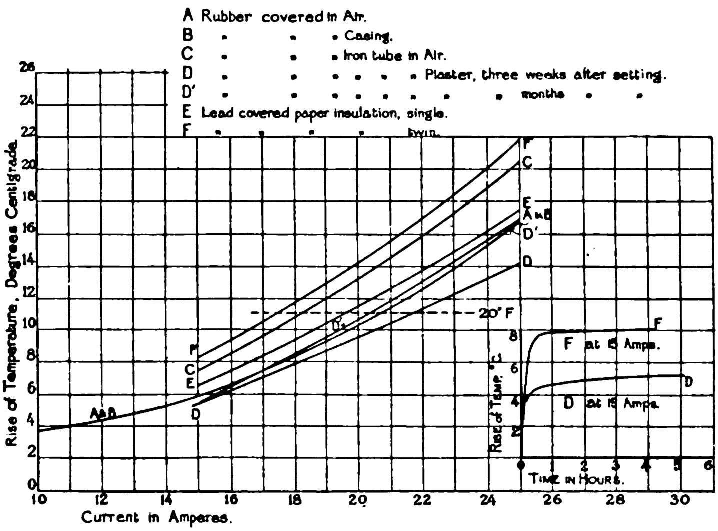


Fig. 3.

In order to ensure that there was no extraneous heating or cooling at the ends, the connections from the cable to the standard resistance were made with cable having the same cross-section as that under test, the joints were wrapped with canvas wrapping, and the potential leads from the cable to the bridge were taken off at a point just inside the joints. Observations were also taken with the potential points taken off at half-way along the length of one of the cables (0·1 sq. in.) and showed that the maximum difference due to cooling at the ends was only 0·1° C.

The regulating resistances for the larger currents were of German silver tubes cooled by water. The rise of temperature in them is extremely small and did not affect the room temperature perceptibly.

* "The Theory of Electric Cables and Networks." London, 1908.

In the case of the smaller cables the regulating resistance was of Eureka strip of ample size for the current.

The current was taken from a large battery, the cells being paralleled to give 6 volts. The current was kept quite steady throughout the tests and was regulated easily to within ± 1 per cent.

An Elliott precision type millivoltmeter was used to measure the current. This instrument was adjusted to give its full-scale deflection for a drop of 0·15 volt, and consequently it was possible to obtain a good reading for any size of current over the whole range required for the various sizes of cables, by using a suitable shunt, or, in some cases,

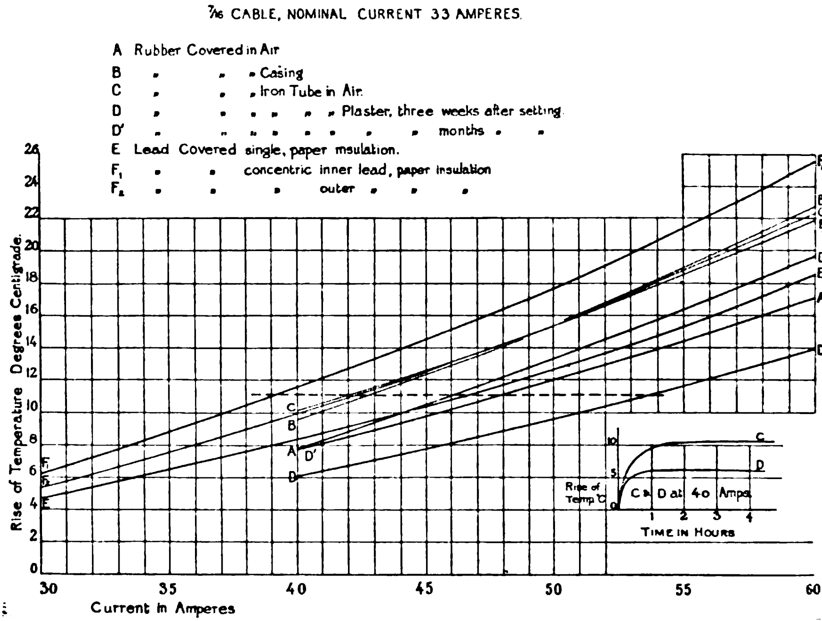


Fig. 4.

by connecting it to the potential terminals of the standard resistance which was used to determine the conductor resistance.

The standard resistances used were constructed of manganin sheet or wire, and were selected to be somewhere near the resistance of the conductor of the cable under test. They varied from 0·01 ohm in the case of a 1/14 cable to 0·00002 ohm in the case of the 1-sq. in. cable.

Tests with Alternating Current.—In order to ascertain if there was any large difference between the heating with direct and alternating current, a test was made with the paper-insulated lead-covered cable and the rubber cable 0·5 sq. in. section with alternating current of 50 cycles per second. The cable was heated by means of the alter-

nating current, the measurement of resistance being made by changing over to direct current immediately before the observation was made. The results agreed with those obtained with direct current to within about 3 per cent., this being within the probable limit to which the alternating current was kept constant.

Further tests on these lines were not proceeded with, as it was evident that for the cables to which the Wiring Rules would apply there is little if any difference between the heating with direct and with alternating current.

Check observations taken at various periods, in some cases after the cable had been tested and put aside coiled up for some months, have agreed very closely with the first observations. The probable accuracy

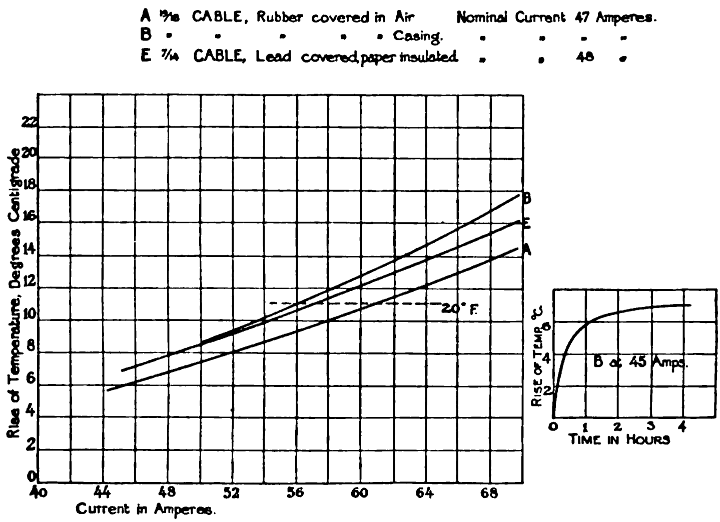


FIG. 5.

of the results is to within ± 1° F. for a rise of 20° F., and 2° F. for a rise of 50° F.

Comparison of Stranded and Solid Wires.—The results of the tests of the three small cables, *i.e.*, 1/14, 3/18, and 7/21, being nearly the same as regards area of the conductor, are shown in the curve in Fig. 2.

In order to make a correct comparison between the solid wire and the different methods of stranding the results have been corrected for the small differences in cross-section between the conductors. It will be seen that the difference in the current required for a given temperature rise is only 3 per cent. between 1/14 and 7/21 cable, the actual temperature difference being only 1° F. with a current of 20 amperes.

Cables with Different Types of Covering.—The results obtained with the 3/18, 7/16, 19/14, and 61/0·101 cables are shown in the curve in

A 19/14 CABLE. Rubber covered in Air. Nominal Current 108 Amperes
B „ „ „ „ „ Casing „ „ „ „
E 19/.082 Lead covered single Cable, paper insulated Nominal Current 113 Amperes.
F_1 19/.082 „ „ concentric „ „ „ „ „ „ „ inner lead.
F_2 „ „ „ „ „ „ „ „ „ „ „ outer „

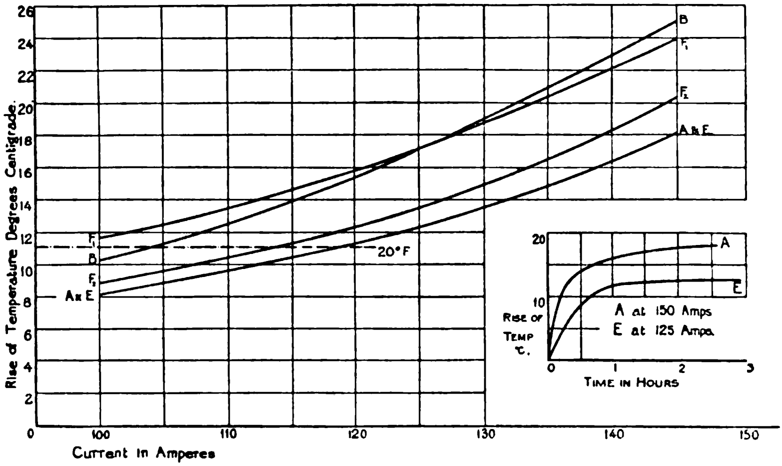


FIG. 6.

A 61/.101 Cable Rubber covered in Air: Nominal Current 425 Amperes.
E „ „ Lead covered „ „ „ „ „ „
F_1 0.5 sq. in Concentric Cable, Lead covered paper insulated, inner lead.
F_2 „ „ „ „ „ „ „ „ outer lead.

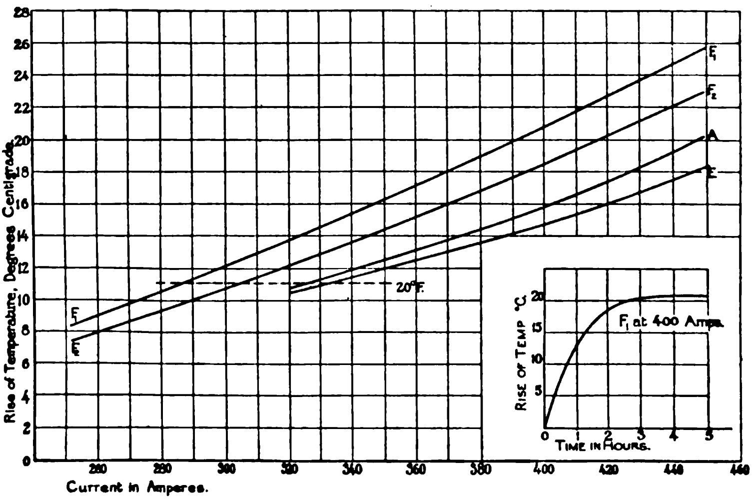


FIG. 7.

Figs. 3, 4, 5, 6, and 7. It will be seen that generally the current-carrying capacity of the rubber cables for a temperature rise of 20° F. is about 10 per cent. less when they are run in casing than when they

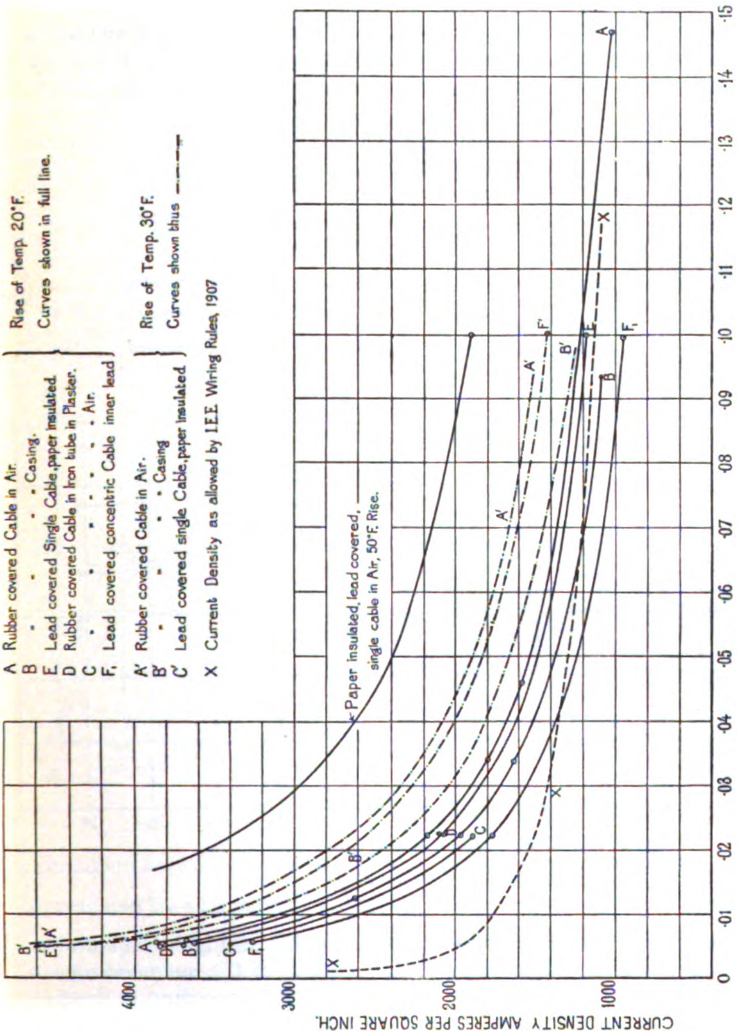


FIG. 8.

are laid out along the floor—*i.e.*, in air (the latter, of course, approximates to the conditions of cables cleated to a wall or in a wood chase). There is very little difference between the rubber- and paper-insulated cables when laid under similar conditions. It is perhaps interesting to

note that the difference between rubber cable in casing and in iron tube in air (*i.e.*, laid along the floor) is very small. When, however, the iron tube is embedded in plaster the cooling is distinctly better, the curve being nearly the same as that obtained with the lead-covered single cable.

Current Density and Sectional Area of Conductor.—Figs. 8 and 9 are curves showing the result for the whole series of cables tested, in current density per square inch of conductor for a given temperature rise.

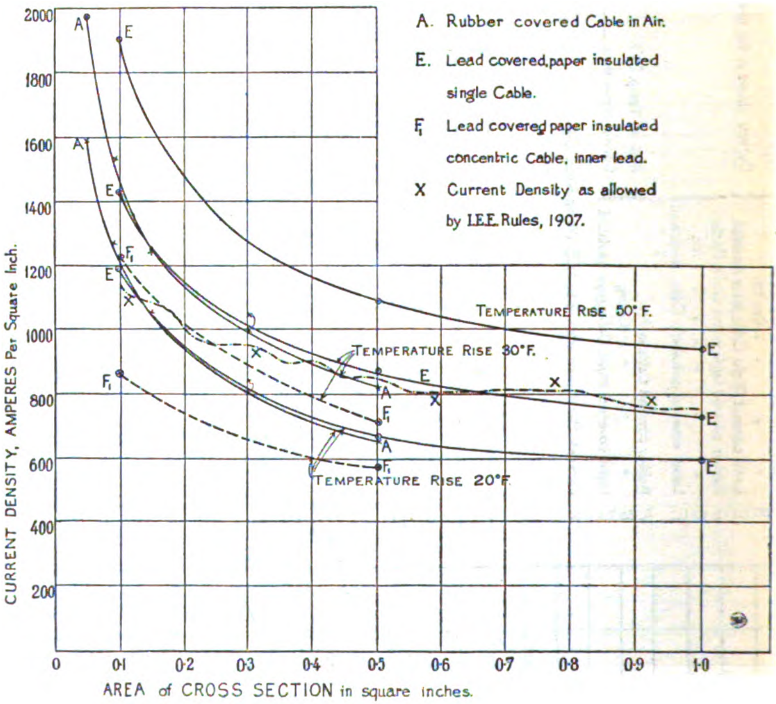


FIG. 9.

Each of the cables examined was run with a steady current until a final maximum rise of temperature above that of the surrounding air was attained. The time required for this varied according to the size of the cable, and may be inferred from the small subsidiary curves of heating shown in curves in Figs. 3, 4, 5, 6, 7 and in Fig. 10, from which it will be seen that it ranged from 2 up to 5 or 6 hours.

This determination of current and temperature rise was repeated four or five times in the case of each cable, with currents so chosen as to give a series of values of final temperature lying suitably over the

range of temperature under consideration, so as to give curves which would allow the values of the current for final temperatures of 20° F., 30° F., and, in the case of the larger-sized lead-covered cables, 50° F., to be obtained by well-conditioned interpolation.

For each type of cable and each condition of running a curve was drawn, showing, for a specified final temperature rise, the connection between the cross-sectional area S and the current density i, i being obtained by dividing I, the current in amperes, by S.

Representation by a General Formula.—It was found that in certain cases—*i.e.*, single rubber-covered cables in air and in wood casing and paper-insulated lead-covered cables, both single and concentric—the

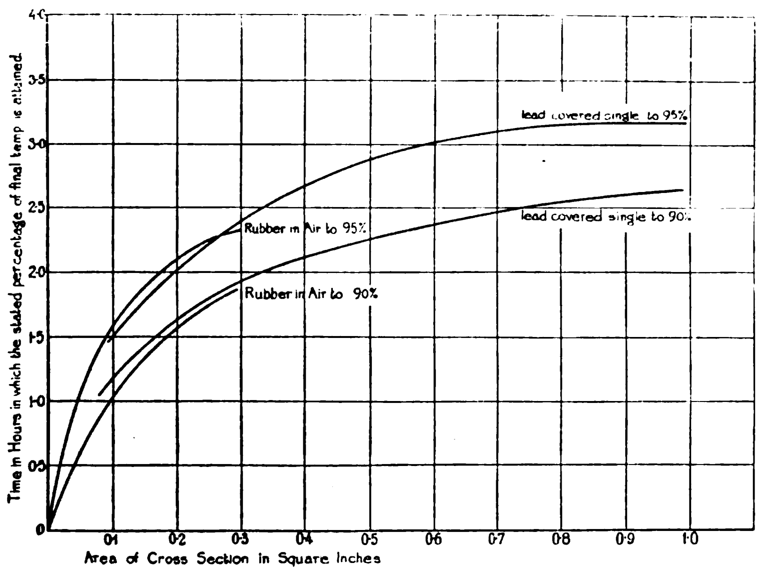


FIG. 10.

connection between cross-section and current density could be fairly represented by a formula of the type $i = K\left(\frac{D}{S}\right)^n$, where n is a constant and K depends on the system of units adopted and the amount of the temperature rise. This is shown in Figs. 11 and 12, where $\log i$ and $\log \frac{D}{S}$ have been plotted. In the four cases considered, viz., that of lead-covered single cables for a temperature rise of 20° F. and of 30° F., and that of rubber cables for a same rise of temperature, it will be seen that the values of $\log i$ and $\log \frac{D}{S}$ follow a linear law very approximately. The slope of the line in each case gives the constant n. K is

deduced in the usual way. If i is the current density in the copper conductor in amperes per square inch, S the cross-section of the copper in square inches, and D the diameter of the outside covering of the cables in inches, the following table shows the value of these constants in the cases indicated:—

Table III.

For Temperature Rise of—

Type of Cable.	20° F.	30° F.	50° F.
Rubber covered in air ...	$i = 364 \left(\frac{D}{S}\right)^{0·616}$	$i = 457 \left(\frac{D}{S}\right)^{0·616}$	—
Rubber covered in casing	$i = 309 \left(\frac{D}{S}\right)^{0·66}$	$i = 358 \left(\frac{D}{S}\right)^{0·66}$	—
Lead covered	$i = 429 \left(\frac{D}{S}\right)^{0·50}$	$i = 536 \left(\frac{D}{S}\right)^{0·50}$	$i = 688 \left(\frac{D}{S}\right)^{0·50}$

For concentric and twin cables the formulæ are the same as for lead-covered single cables if S, the total cross-section, is taken as being both that of the lead and the return conductors.

If, however, i is in amperes per square centimetre, S in square centimetres, and D in centimetres, the constants become—

Table IV.

For Temperature Rise of—

Type of Cable.	11·1° C.	16·7° C.	27·7° C.
Rubber covered in air ...	$i = 101 \left(\frac{D}{S}\right)^{0·616}$	$i = 126 \left(\frac{D}{S}\right)^{0·616}$	—
Rubber covered in casing	$i = 91 \left(\frac{D}{S}\right)^{0·66}$	$i = 106 \left(\frac{D}{S}\right)^{0·66}$	—
Lead covered in air ...	$i = 110 \left(\frac{D}{S}\right)^{0·50}$	$i = 137 \left(\frac{D}{S}\right)^{0·50}$	$i = 175 \left(\frac{D}{S}\right)^{0·50}$

The reasons which suggest the use of this particular type of formula may now be indicated.

If the heat developed by the passage of the current in a centimetre length of the conductor be H joules per second; if D be the outer diameter of the covered cable, and d that of the copper conductor, both

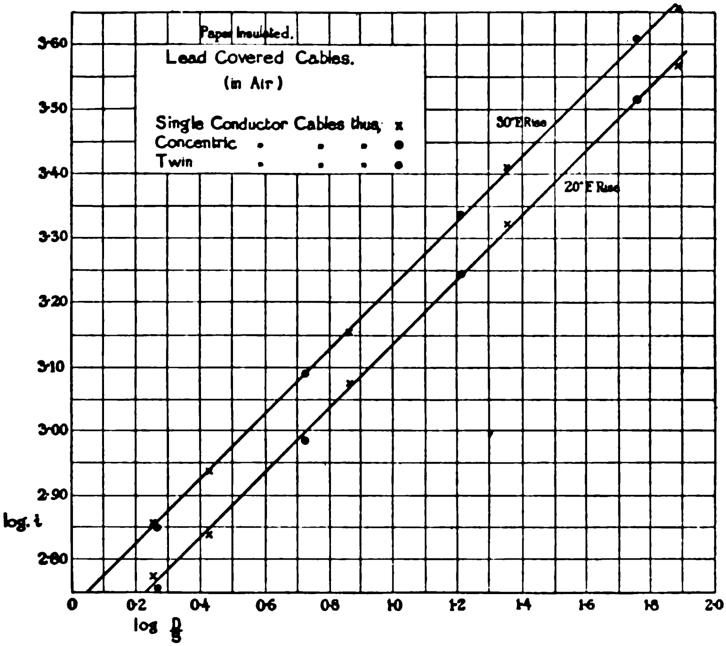

Paper Insulated.
Lead Covered Cables.
(in Air)
Single Conductor Cables thus x
Concentric
Twin
30°F Rise
20°F Rise
log. i
log D/S

FIG. 11.

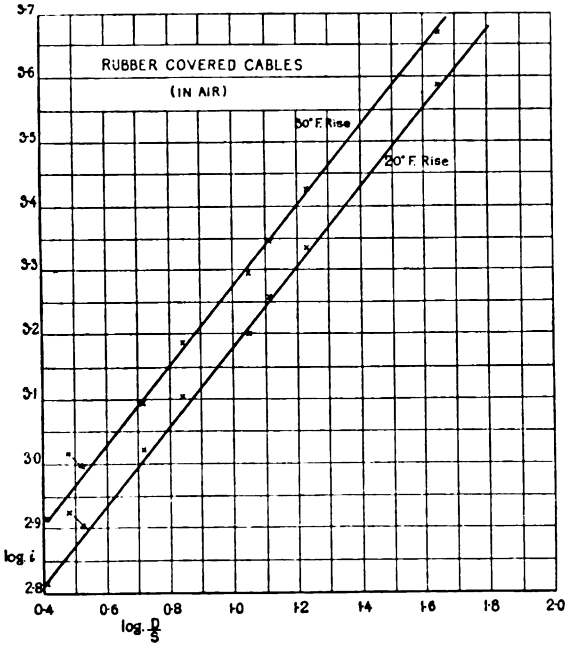

RUBBER COVERED CABLES
(IN AIR)
30° F. Rise
20° F. Rise
log. i
log. D/S

FIG. 12.

in centimetres; if T be the temperature of the copper, t the temperature of the outer surface of the cover, and θ that of the surrounding air in °C., I the current in amperes, ρ the specific resistance of the copper, and a its temperature coefficient; we then have—

$$H = 0{\cdot}24\, I^2 R = \frac{0{\cdot}24\, I^2\, 4 \rho (1 + a T)}{\pi d^2} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

In the final stable condition, where, the length of the cable being long in comparison with its diameter, we may assume that this quantity of heat passes radially through the cover in each second; and if k is the thermal conductivity of this covering, we have by a well-known formula—

$$H = \frac{2 \pi k (T - t)}{\log_e \frac{D}{d}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

For the restricted range of temperature under consideration it was assumed that the loss of heat from the surface by radiation, convection, and conduction is to a first approximation proportional to the difference between the temperature of the cable cover and that of the surrounding air. We therefore have for the loss of heat in joules per second—

$$H = h (t - \theta) \pi D \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

where h is a constant.

These three equations must be simultaneously satisfied. By equations (1) and (2) we have—

$$T - t = \frac{0{\cdot}24\, I^2\, 2 \rho (1 + a T)}{\pi^2 k d^2} \log_e \frac{D}{d} \quad . \quad . \quad . \quad . \quad . \quad (4)$$

By equations (1) and (3) we have—

$$t - \theta = \frac{0{\cdot}24\, I^2\, 4 \rho (1 + a T)}{h \pi^2 d^2 D} \quad . \quad . \quad . \quad . \quad . \quad (5)$$

By the addition of (4) and (5) we have—

$$T - \theta = \frac{0{\cdot}48\, I^2 \rho (1 + a T)}{h \pi^2 d^2 D k} \left(h D \log_e \frac{D}{d} + 2 k\right) \quad . \quad . \quad . \quad . \quad (6)$$

$T - \theta$ is the temperature rise, and hence we have—

$$I^2 = \frac{T - \theta}{1 + a T} \cdot \frac{h \pi^2 d^2 D k}{0{\cdot}48 \rho} \cdot \frac{1}{\left(h D \log_e \frac{D}{d} + 2 k\right)} \quad . \quad . \quad . \quad (7)$$

or since—

$$i = \frac{4 I}{\pi d^2}$$

$$i = \frac{4}{d} \sqrt{\frac{T - \theta}{1 + a T}} \cdot \sqrt{\frac{h D k}{0{\cdot}48 \rho \left(h D \log_e \frac{D}{d} + 2 k\right)}} \quad . \quad (8)$$

where k and h are in calories per sec.

i.e.—

$$i = K_1\sqrt{\frac{T-\theta}{1+aT}}\sqrt{\frac{D}{d^2\left(D\log_e\frac{D}{d}+\frac{2k}{h}\right)}} \quad . \quad . \quad . \quad (9)$$

where K_1 includes the factor $\sqrt{\frac{k}{\rho}}$, and is a constant for a particular type of cable.

If in this expression we consider T and θ as constant, which is the case for a definite rise of temperature under uniform conditions, we have—

$$i = K_2\sqrt{\frac{D}{d^2\left(D\log_e\frac{D}{d}+\frac{2k}{h}\right)}}$$

or—

$$i = K_2\sqrt{\frac{D}{d^2}}\sqrt{\frac{1}{\left(D\log_e\frac{D}{d}+\frac{2k}{h}\right)}}$$

The first two factors of this expression correspond to the formula found, viz.—

$$i = k\left(\frac{D}{S}\right)^n$$

since S is proportional to d^2. In the case of paper-insulated lead-covered cable where a better uniformity of proportioning in the thickness of the covering than in the case of the rubber may be expected to be the rule, the value for n for all three values of T tested (corresponding to 20° F., 30° F. and 50° F.) was very closely 0·5 as required by the theoretically obtained formula.

The factor $\sqrt{\frac{1}{D\log_e\frac{D}{d}+2\frac{k}{h}}}$ was found to be very nearly constant for a wide range of cable sizes. As an example the values of D and d for a lead-covered single cable have been taken from a manufacturer's list for sizes of cable ranging from one of 0·025 sq. in. cross-section of conductor to one of 1·0 sq. in., and from these the values of $D\log_e\frac{D}{a}$ have been calculated. As will be mentioned later, approximate values for the thermal constants k and h were determined which gave 2·5 as a mean value of the term $2\frac{k}{h}$. This enabled the factor

$\sqrt{\frac{1}{D\log_e\frac{D}{d}+2\frac{k}{h}}}$ to be calculated, and in Fig. 13 it is shown plotted against S the area of cross-section. As will be seen, the variation

in the value of this factor is of the order of 6 per cent., and wider variations in its value will account for the divergence of the formula—

$$i = \mathrm{K}\left(\frac{\mathrm{D}}{\mathrm{S}}\right)^n$$

from the theoretical square root form.

As the term K in this formula includes as a factor the term $\sqrt{\frac{\mathrm{T}-\theta}{1+a\mathrm{T}}}$ it is of interest in the case of a particular type of cable

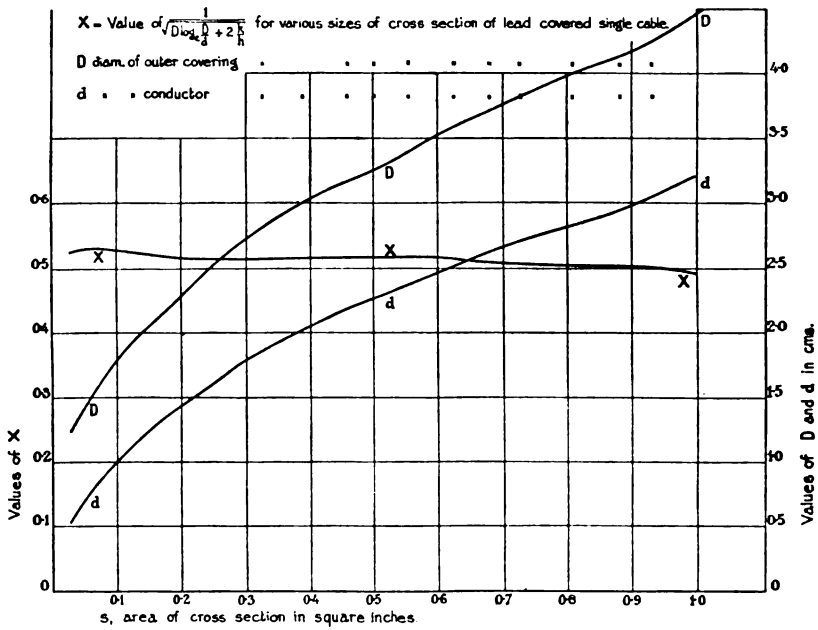


FIG. 13.

to compare the ratio of different values of K as given in Table III. with the ratios of different values o $\sqrt{\frac{\mathrm{T}-\theta}{1+a\mathrm{T}}}$ obtained by evaluation for the corresponding values of $\mathrm{T}-\theta$, the temperature rise. Thus taking θ as 18° C. (64° F.), the values of $\sqrt{\frac{\mathrm{T}-\theta}{1+a\mathrm{T}}}$, called x_{20}, x_{30}, x_{50}, have been calculated for values of $\mathrm{T}-\theta$, corresponding to 20° F., 30° F., and 50° F. (11·1° C., 16·7° C., and 27·7° C.) respectively. In the general formula given in Table III.—

$$i = \mathrm{K}\left(\frac{\mathrm{D}}{\mathrm{S}}\right)^n$$

the various values of K applying to the temperature rises specified have been designated K_{20}, K_{30}, and K_{50}, and are set out in the following table. Also the ratios of K_{20} to K_{30} and of K_{20} to K_{50} are shown and the corresponding ratios of x_{20} to x_{30} and of x_{20} to x_{50}, and it will be seen that the two sets of ratios are in fair agreement, thus confirming the general validity of the formula.

Thermal Constants.—In order to determine at least approximately the values of the thermal constants involved, the temperature of the outer surface of the cable was also observed. This was done by winding a fine copper wire, size No. 44 S.W.G., round the cable so that it was for its whole length in good thermal contact with the braiding or the lead of the cable cover. From the change in resistance of this wire, measured on the Wheatstone Bridge, its temperature and that of the surface of the cable with which it was in contact could be readily deduced. This enabled the thermal constant h, the

TABLE V.

	20° F. 11·1° C.		30° F. 16·7° C.		50° F. 27·7° C.		$\frac{K_{30}}{K_{20}}$	$\frac{x_{30}}{x_{20}}$	$\frac{K_{50}}{K_{20}}$	$\frac{x_{50}}{x_{20}}$
	K_{20}.	x_{20}.	K_{30}.	x_{30}.	K_{50}.	x_{50}.				
Rubber covered in air	364	—	457	—	—	—	1·25	—	—	—
Rubber covered in casing ...	309	—	358	—	—	—	1·16	—	—	—
Lead covered in air	429	—	536	—	688	—	1·25	—	1·61	—
From $\sqrt{\frac{T-\theta}{1+aT}}$...	—	3·26	—	3·95	—	5·0	—	1·21	—	1·54

emission of heat in joules per °C. per unit area of surface, and also k, the constant of heat conductivity, to be determined. The following values and the process by which they were arrived at may be of interest.

Thermal constants of a lead-covered cable, paper insulation, size of conductor, 1 sq. in. cross-section.

L length (total), 915 cms.
D_l outer diameter of lead cover, 4·6 cms.
D_p inner diameter of lead cover, 3·9 „
D_c diameter of copper conductor, 3·25 cms.

When running at a current $I = 850$ amperes, the resistance R was $3·02 \times 10^{-7}$ ohms per centimetre; the temperature of the conductor T was 39·9° C.; the temperature of the outer surface of the lead t_0 was 34·4° C., and the temperature of the air θ was 17·7° C. The heat dissipated per second per centimetre length of cable was—

$$H = 0·24\, I^2 R = 0·24 \times 850^2 \times 3·02 \times 10^{-7} \text{ gram-calories}$$
$$= 0·052 \text{ gram-calories.}$$

The temperature t_1 of the inner surface of the lead cover was first obtained—

$$t_0 - t_1 = \frac{H}{2\pi K} \log_e \frac{D_l}{D_p}.$$

For lead the coefficient of thermal conductivity $k = 0\cdot08$, so that—

$$t_0 - t_1 = \left(\frac{0\cdot052}{2\pi \times 0\cdot08} \log_e \frac{4\cdot6}{3\cdot9}\right) = 0\cdot017.$$

Therefore t_1 may be taken as equal to t_0, $t_1 = t_0 = t$, say, so that the thermal conductivity of oil-impregnated paper—

$$k = \frac{H}{2\pi(T - t)} \log_e \frac{D_p}{D_c}$$

$= 0\cdot00027$ gm.-calories per cm. per sec. per °C.

Emissivity constants of surface of the lead cover—

$$h = \frac{H}{\pi D_l (t - \theta)}$$

$= 0\cdot00021$ gm.-calories per cm.^{2} per sec. per °C.

The same two constants for this cable when running at 750 amperes came out as—

$k = 0\cdot00024.$
$h = 0\cdot00021.$

For a smaller sized lead-covered cable (7/16) the constants at 60 amperes came out as—

$k = 0\cdot00032.$
$h = 0\cdot00037.$

For a 37/15 rubber-covered cable running at 188 amperes the values came out as follows :—

$k = 0\cdot00028.$
$h = 0\cdot00026.$

In this case k represents the average conductivity through the various materials of which the cover is composed.

Cooling Effect of Covering.—The determination of the constants h and k enabled us to investigate the effect of the covering in cooling the cable, which was indicated by Professor Forbes in 1884. On account of the discrepancies in the values of h and k which we obtained—discrepancies which were inevitable in view of the want of homogeneity and of exact uniformity in disposition of the covering—the results set forth are necessarily only of an approximate and qualitative character.

Starting with equation (8), page 724, we can write it thus :—

$$i = \frac{4}{d}\sqrt{\frac{T - \theta}{1 + \alpha T}} \sqrt{\frac{D k}{\cdot48 \rho \left(D \log_e \frac{D}{d} + 2\frac{k}{h}\right)}} \quad . \quad . \quad . \quad (10)$$

where i is the current density in amperes per square centimetre, D the diameter of the finished cable, d the diameter of the copper conductor, regarded as cylindrical in the case of the stranded cables.

If here we take—

- $T-\theta$ the temperature rise, 11·1° C. (20° F.),
- θ temperature of air, 18·9° C. (66° F.),
- T temperature of conductor, 30·0° C. (86° F.),
- ρ resistance of conductor, $1·548 \times 10^{-6}$ ohm cms.,
- a temperature coefficient of resistance of conductor, 0·004 per °C.,
- h constant of emissivity (rubber covering), 0·00026 gm.-calories per cm.² per sec. per °C.
- k thermal conductivity (rubber covering), 0·00028 gm.-calories per cm. per sec. per °C.

the equation becomes—

$$i = 4\sqrt{\frac{11·1}{1·12}} \cdot \sqrt{\frac{0·00028 \times 10^6}{0·48 \times 1·584}}\,\frac{1}{d}\sqrt{\frac{D}{D \log_e \frac{D}{d} + 2·15}}$$

or—

$$i = \frac{242}{d}\sqrt{\frac{D}{D \log_e \frac{D}{d} + 2·15}} \quad \ldots\ldots \quad (11)$$

which enables us to calculate, in the case of a rubber-covered cable to which the constants detailed above apply, the current density for any given values of D and d; or, taking d, the diameter of the copper (*i.e.*, the size of the cable), as constant, enables us to trace out the effect on the current density due to varying the size of D which is determined by the thickness of the insulation and covering.

This has been done for seven cases representing seven different sizes of cable ranging from $d=0·203$ cm. (corresponding to a single 1/14 cable) to $d=2·15$ cm., which nearly corresponds to a 1 sq. in. cable, and the results are set forth in Fig. 14, in which each curve shows the variation of current density required to produce a given temperature rise in the copper due to varying the diameter of the finished cable by varying the thickness of the insulation and covering. The dotted line marks a point on each curve corresponding to an average representative value of the outside diameter as taken from a manufacturer's list.

It is to be noticed that, in the case of the smaller cables, increasing the size of the covering from this normal value would apparently increase considerably the permissible current density; but in the case of the larger cables the effect of doing so would be much less. In each curve there is a maximum point at $D=2·15$ cm., *i.e.*, $D=2\frac{k}{h}$, a result which is confirmed by differentiating i as expressed in equa-

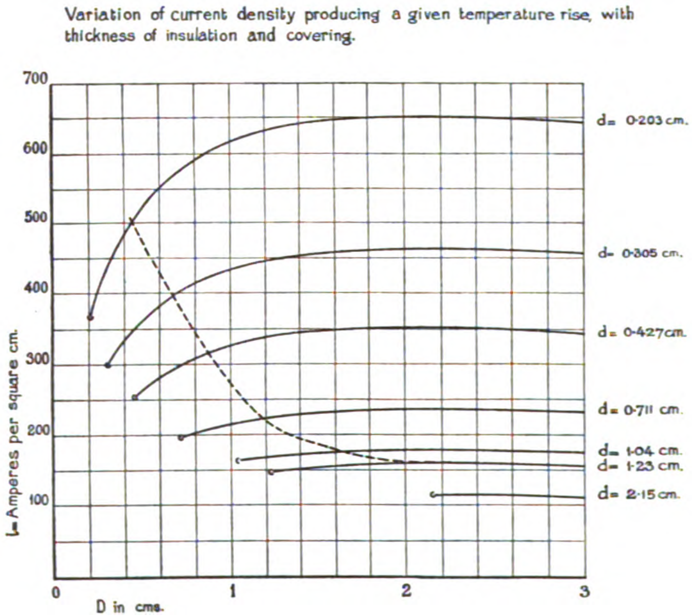

Variation of current density producing a given temperature rise, with thickness of insulation and covering.
I = Amperes per square cm.
700
600
500
400
300
200
100
0
1
2
3
D in cms.
d = 0·203 cm.
d = 0·305 cm.
d = 0·427 cm.
d = 0·711 cm.
d = 1·04 cm.
d = 1·23 cm.
d = 2·15 cm.

FIG. 14.

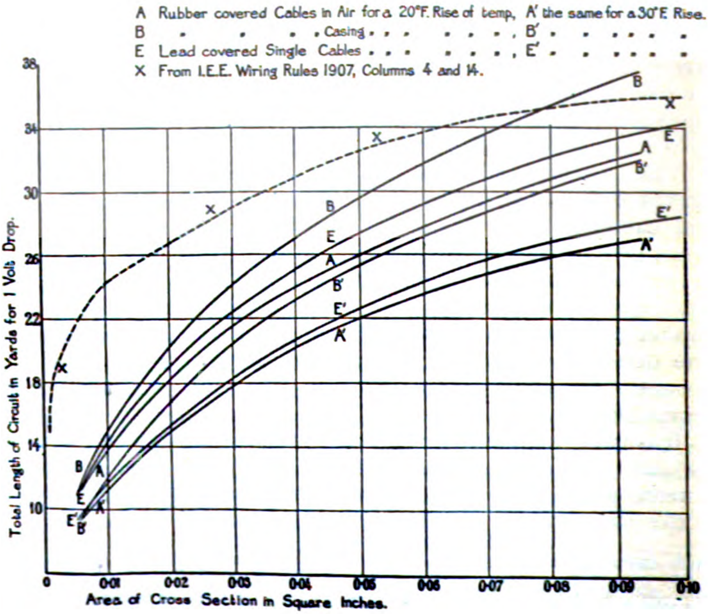

A Rubber covered Cables in Air for a 20°F. Rise of temp, A' the same for a 30°F. Rise.
B " " " Casing " " " " " " " B' " " " " " "
E Lead covered Single Cables " " " " " " " E' " " " " " "
X From I.E.E. Wiring Rules 1907, Columns 4 and 14.
Total Length of Circuit in Yards for 1 Volt Drop.
38
34
30
26
22
18
14
10
0
0·01
0·02
0·03
0·04
0·05
0·06
0·07
0·08
0·09
0·10
Area of Cross Section in Square Inches.

FIG. 15.

tion (10) with regard to D, with d constant. It would thus follow that in cables where D is equal to or greater than $2\,\frac{k}{h}$ any further increase in the thickness of the covering would diminish instead of increasing the permissible current density.

Comparison of 1907 Wiring Rules with the Results now Obtained.—The dotted curves marked "X" in Figs. 8 and 9 give the current-

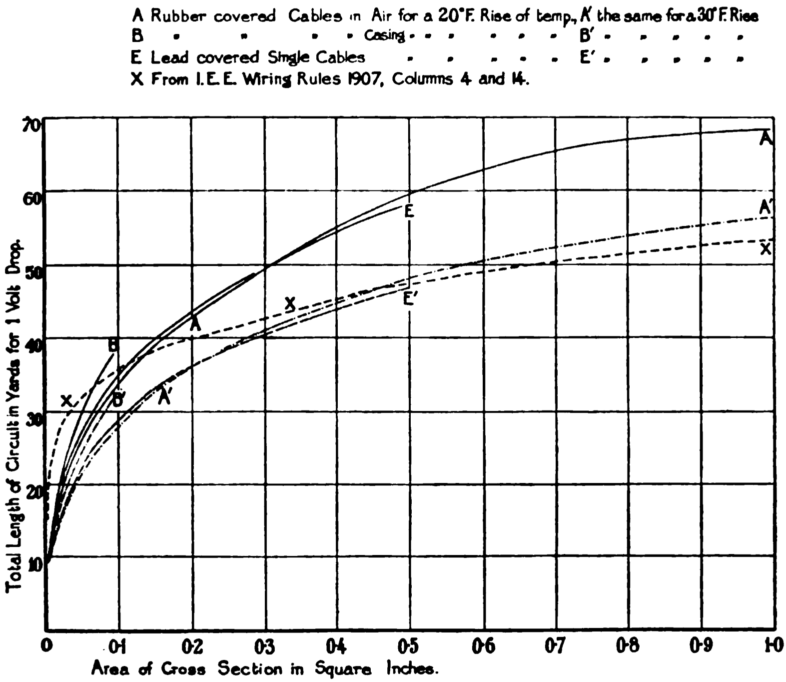


FIG. 16.

density allowed by the 1907 Wiring Rules. It will be seen that this gives a temperature rise of about 20° F. for cables of from 0·05 sq. in. to 0·15 sq. in. rising to rather more than 30° F. for cables up to 1 sq. in. section. For cables smaller than 0·05 sq. in. the temperature-rise with the current density at present allowed is much less than 20° F. (in the case of a 3/18 cable in casing it is only about 7° F.).

Voltage Drop.—The total length, lead and return, for a drop of 1 volt for a rise of temperature of both 20° F. and 30° F., together with that given by the 1907 Wiring Rules, are shown on the curves in Figs. 15 and 16.

Conductivity of the Conductors.—The conductivities of the wires in

five of the cables were tested, and they all were found to be between 99 and 100·3 per cent.

For the purpose of these tests a length of about 130 cm. was cut off the cables, the insulation stripped off, and the conductivity of each wire determined separately.

General Conclusions.—The conditions under which the tests were made were those indicated or approved by the Wiring Rules Committee as being the normal conditions in general use, and the results show the heating of the various types of cable under these conditions. It is, of course, obvious that the tests do not meet all conditions under which cables are or may be laid. The data furnished, however, are

CURVES SHOWING HEATING OF 19/14s CABLE LAID UNDER VARIOUS CONDITIONS.

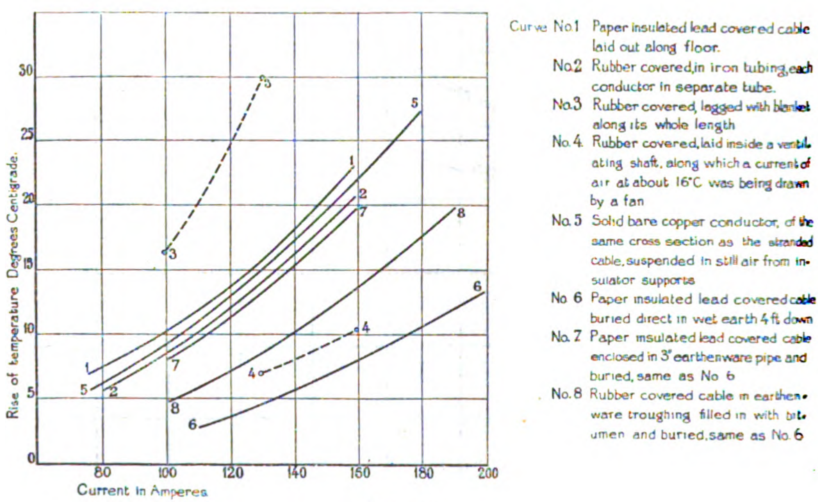


FIG. 17.

probably sufficient to enable any abnormal conditions met with in practice to be dealt with.

Some Tests under Extreme Conditions.—In the curve on Fig. 17 are shown results obtained with 19/14 cable laid under various conditions. These results were preliminary and the observations were not made so accurately as in the case of those before described. They were made with a view to obtaining an idea of the extent of the variation that existed under various conditions.

It will be seen that there are very large differences between the various methods of laying. The curves 4 and 5 are, of course, very extreme cases and would probably not be met with in practice. No. 5 would, as pointed out by Dr. Russell, be subject to very large variations if it were in a draught of air.

The question of the heating of buried cables is a most important one. It has been somewhat outside the scope of the present work, however. So far as the authors are aware, no attempt has been made by the engineers responsible for large cable systems to determine the temperature rise in the cables as laid. It would not be very difficult to obtain data of this sort, which would be extremely valuable. A test of the voltage drop along a length of cable from the distributing station to the first distributing box at various currents or conditions of loading could be easily made. It would, however, probably be insufficient to take the total volts at each end of the cable as the difference would be so small, but if a small wire were run back along the cable the voltage drop could be taken sufficiently accurately on a low-reading voltmeter.

Intermittent Load Tests.—The extent to which the nominal rating of cables might be modified where the load is intermittent in character

VARIATION OF TEMPERATURE: 19/14s Rubber covered Cable running intermittently.

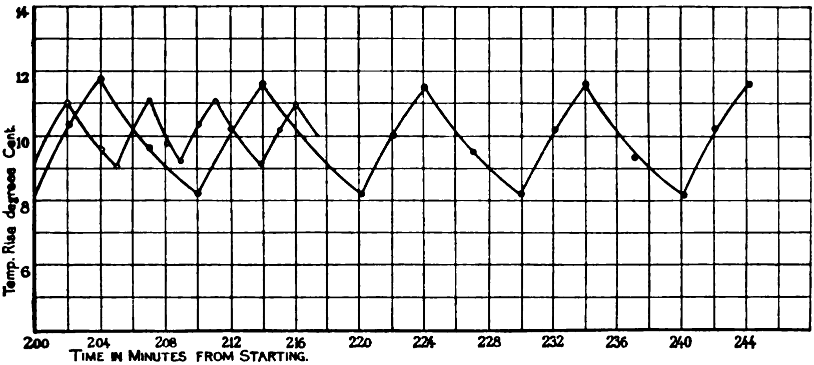


FIG. 18.

was also investigated. The larger sizes of cables only attain their final steady temperature after running for some hours, the time actually required depending on the size of the cable and the thermal properties of the materials with which it is covered. In Fig. 10, before referred to, the time in hours required by certain cables to reach a specified percentage of the final temperature is shown. As a consequence of this effect, cables which are only working intermittently may be run considerably above their normal rating without at any time exceeding the maximum temperature rise permissible. The subject in relation to motors has already been discussed in a paper read before the Institution by Mr. Rud. Goldschmidt,* who, as typical of the conditions under which crane machinery works, considered the case where a period of 3 minutes' running is followed by 7 minutes' rest. The authors of the present paper took as a more severe case a period of 4 minutes' running followed by 6 minutes' rest, and, as a variation of

* *Journal of the Institution of Electrical Engineers*, vol. 34, p. 660, 1905.

this, a period of 2 minutes' running followed by 3 minutes' rest; and in each case measured the rise and fall of temperature going on in the cable under these conditions of working. The general method was the same as that followed for the continuous load tests already described. A 19/14 rubber-covered cable, the nominal rating of which under the new rules is 113 amperes, was chosen for the test. After a trial run at 33 per cent. overload (*i.e.*, at 150 amperes), which was found to give a maximum temperature rise well below the limit allowed, the temperature was finally taken for a 50 per cent. overload. The curves in Fig. 18 show the rise and fall of temperature during the working and idle part of the two periods considered. In each case the cable had been run, in the way indicated, for some hours previously, so that the alterations in the value of the temperature in successive periods fell between constant limits. It will be seen that in the shorter period the maximum part of the temperature curve just reaches the 20° F. (11·1° C.) limit. In the case of the longer period that limit is slightly exceeded.

The thanks of the authors are due to the members of the Wiring Rules Committee, at whose request the investigation was undertaken, for many useful criticisms and suggestions; to Dr. Glazebrook for his kind help and interest in the work, and to Mr. A. Campbell for several suggestions and criticisms in revising the proofs of the paper.

List of references to papers which have been quoted, or which were considered during the investigation:—

FORBES, Professor G. "On the Relation which Ought to Subsist Between the Strength of an Electric Current and the Diameter of Conductors, to Prevent Overheating." (*Journal of the Institution of Electrical Engineers*, vol. 13, pp. 232–262, 1884.)

KELVIN, LORD. "On the Economy of Metal in Conductors of Electricity." (*British Association Report*, 1881, pp. 526–528.)

KENNELLY, A. E. "The Heating of Conductors by Electric Currents." (*Electrical World*, vol. 14, pp. 135, 336, 355, 372, and 386; 1889.)

KENNELLY, A. E. "On the Carrying Capacity of Electric Cables Submerged, Buried, or Suspended in Air." (*Electrical World*, vol. 22, pp. 183 and 201, 1893.)

KENNELLY, A. E., WRIGHT, C. A., BYLEVELT, V. S. VAN. "The Convection of Heat from Small Copper Wires." (*Transactions of the American Institute of Electrical Engineers*, vol. 28, pp. 363–399, 1909.)

PORTER, Professor A. W. "On the Lagging of Thin Wires and Narrow Pipes" (Physical Society). [*Electrical Review*, vol. 63, p. 921, 1908.]

PORTER, Professor A. W. "On the Lagging of Pipes and Wires." (*Philosophical Magazine*, vol. 20, p. 511, 1910.)

PREECE, Sir W. H. "On the Heating Effects of Electric Currents." (*Electrician*, vol. 20, pp. 386–787, 1888.)

ROY, L. "Récherches sur les propriétés thermomécaniques des corps solides." (*Bulletin de la Société Internationale des Electriciens*, vol. 10, p. 504, 1910.)

RUSSELL, A. "The Theory of Electric Cables and Networks." (Constable & Co. London, 1908.)

RUSSELL, A. "The Convection of Heat from a Body cooled by a Stream of Fluid." (*Proceedings of the Physical Society*, vol. 22, p. 432, 1910.)

DISCUSSION.

Mr. C. P. SPARKS: I have few criticisms to offer on Mr. Melsom's paper. But I wish to draw attention, in opening this discussion, to the exceptional nature of this paper. First of all, it has been written and brought before the members at the request of a Committee of this Institution. Mr. Melsom does not tell quite the whole story in the paper. The results put forward are the outcome of an investigation which has lasted over two years. The Wiring Rules Committee have faced this question of the current density of conductors on several occasions. I am familiar with their efforts because I have served an apprenticeship on this Committee of over twenty years. The difficulty of the position was the expense and time taken for a thorough investigation; and it was not until we enlisted the help of the National Physical Laboratory that it was feasible to investigate the matter thoroughly. The Committee consider that the industry owes a debt of gratitude to the National Physical Laboratory, Dr. Glazebrook, and his assistants, for having made this investigation for the benefit of the industry. Further, we have been assisted by cable-makers. Any materials required, sometimes of an expensive character, have been willingly provided by the leading cable-makers, at the request of the Institution, to help this investigation. And again, we feel largely indebted to the public spirit of the cable-makers for helping us in this way. With regard for the reasons for this investigation, I may say that in the early days the industry was almost entirely a lighting industry, and in that case the governing factor was a question of pressure drop; the question of heating hardly came in at all. The rules that were laid down were a compromise, based upon early investigations, and as will be seen from the curves in the paper they were only an approximation. Attention has been drawn in some quarters to the fact that the new Wiring Rules permit what seems to be a very high-current density in the smaller conductors. They do not point out that at the same time they also lower the current density of the larger rubber cables. A study of this paper will show that even with this big advance in current density in the smaller conductors we are still working on a very conservative basis. For instance, 20° F. temperature rise for rubber, and 30° F. for paper is very small indeed. The principal factor we deal with is the variation of the surrounding conditions. For instance, we take it that it is safe to work on this standard up to an air temperature of 100° F. So, after all, the 20° F. heating at these higher current Mr. Sparks.

Mr. Sparks. densities is still a very moderate figure. As to the reason for this change, it has been suggested that it has been brought about by the wiring contractor. The real reason is the largely increased use of electricity for power and heating purposes. The question of pressure drop, although of importance, is not of the same importance as it is in a lighting proposition. And it is the engineers of the electric power and supply companies who, being alive to the fact that it does not help on the industry to have idle copper, are responsible for bringing us up to date. The revision has been on a scientific basis, and an exhaustive description furnished as to the basis on which these new tables are founded. The paper has been written so that we may have a record for future committees and for the information of all concerned in the industry. With regard to safety, I think the public may feel well satisfied as to that. The Committee of the Institution report to the Council, the Council consider the matter and adopt the rules for the Institution. But before the rules were issued they were adopted by some forty-nine of the leading insurance companies. Two hundred municipal undertakings represented by the Council of the Municipal Electrical Association also adhere to the new standard, and the leading power and supply companies. I think that it is impossible to get such a consensus of opinion on the part of insurance companies and supply undertakings in adopting these rules as a standard unless they are based on a sound and practical foundation. Before concluding, there is one further matter I would like to refer to. We hope that when another revision takes place we shall be able to go even further than we have to-day. With the further help of the National Physical Laboratory we hope to investigate the question of critical temperature. It is not a thing which can be undertaken lightly, because it requires years. We have laid down a more or less arbitrary standard with regard to the temperature. We give a safe working temperature of 120° F. for rubber and 130° F. for paper. The question of deterioration of those two materials over very long periods is to be investigated, I hope, with the help of the National Physical Laboratory, and we may find on further revision that we are able to go beyond the present limits of 20° F. and 30° F. respectively which have been indicated as the basis for the present rules. I am unable to criticise the paper because I have had many interviews with Mr. Melsom, and in some way I am responsible, as Chairman of the Committee, for suggesting the method by which the work has been carried out.

Mr. Human. Mr. H. HUMAN : This subject is one in which I take a very considerable interest, not alone from the mere point of view of the Fire Office, but also from the fact that during the past twenty-seven years I have had a hand in many wiring rules, and I have also published some current density tables based upon a temperature limit. In 1884, when I was engaged in bringing out a set of rules for my office (we were in those days all running on our own in these matters), I realised that to limit the current per conductor on a basis of a certain number of amperes per square inch was a fallacy, for it implies that the temperature of wires

for a given current is proportional to the sectional area of those wires, which, however, is not the case, and the only rational way to deal with it is by means of a temperature limit. But merely to formulate a rule stating what that limit is would be of very little value. It must be translated into figures by way of a table complying with the rule. Therefore I got out a table based on the work of Professor Forbes, and I adopted the temperature limit of 10° C. due to current. That table existed until 1890, when I found I had to recast it from top to bottom, and for this reason Professor Forbes had been working upon gutta-percha as the insulating medium. Of course we had long got out of gutta percha for our cables. Then Dr. Kennelly in America had tackled the subject afresh from the point of view of rubber-covered conductors in casings, and the results naturally differed from those of Professor Forbes. Therefore I got out a new table based upon the data of Dr. Kennelly, and, if I remember rightly, that table was immortalised in Rankin. But in 1897 this Institution issued a new revised edition of their rules, and with it a table of current densities based upon a limit of rise of temperature due to current of 10° F. I therefore scrapped my rules and table and adopted those of this Institution for the sake of uniformity. I naturally regarded that table as above suspicion, coming from whence it did. But when, later, I was privileged to assist in a further revision of those rules, I endeavoured to ascertain what was the basis, or rather what were the data upon which that table was framed, but without success; nobody seemed to know. And therefore when this very recent revision was taken in hand, we all recognised that, as we were carrying the temperature limit from 10° to 20° F., it was most essential that we should have perfectly reliable data on which to frame a table to meet the new rule, and we did the very best thing we could do, and that was to put the matter into the hands of Dr. Glazebrook. Well, the result is before you this evening. Let me say this, that, whatever our sins of omission or commission may be in connection with the rules, we can plume ourselves on the fact that it is entirely due to our initiation that the science of electricity has been enriched by this work of the National Physical Laboratory, and that work will, in my opinion, live as long as we are committed to rubber and copper. I am particularly pleased that the authors, who have apparently borne the brunt of the work, have been permitted to put before the world in full detail their method of procedure; because any one reading this paper must be impressed with the exceeding care which they exercised in eliminating all possible sources of error. We now know where we stand in this matter of temperature; but we also know where we have been standing, and that is not quite such pleasing reading. It is now perfectly obvious that the old table was based upon insufficient data; and when I looked at Fig. 9 and examined that dotted line marked X, which, by courtesy, we must call a curve, but which to my view more resembles a piece of corrugated iron which has been in a fire, and when I realised that that is the thing upon which I have rested this many a day, I felt very sorry for myself. But there is just this consola-

Mr. Human. tion in the fact, that when we come to look at the current densities of the smaller class wires under the old table, it will be seen they carry a very ample margin for safety. And even when we come to the 19's, it will be seen that even those, under the old current density, are well within the new temperature limit of 20° F. So no great harm has been done. I may say that those who look at this matter from the Fire Office point of view will feel greatly indebted to these gentlemen for the splendid work they have done, and I may tell them that that work will extend far and wide; far beyond the confines of this Empire. For there are a number of foreign fire associations which take their inspiration from the Fire Office Committee here in London on many things; but in matters electrical they usually take their inspiration from this Institution, and however they may regard the new rules, one thing I am certain of, and that is that they will welcome the new table, and for the reason that it bears the hall-mark of the National Physical Laboratory.

Mr. Snell. Mr. J. F. C. SNELL: I should like to endorse the remarks which have fallen from Mr. Sparks, who has piloted the Wiring Rules Committee for so many years, as to the gratitude he ought to feel not only to the authors of this paper for this very careful investigation, but also to the National Physical Laboratory, and to Dr. Glazebrook in particular, for all the help given to that Committee. Although we now find that the larger sections of cables have been, perhaps, badly rated in the past under the old Wiring Rules, we can console ourselves at any rate with this thought that no evil result appears to have happened. But it is well that we should know exactly where we stand. As Mr. Human remarked just now, Fig. 9 in the paper shows that we have been sailing to some extent under false colours. Now, this investigation of Mr. Melsom and Mr. Booth will put us right in this respect, and the new issue of the Wiring Rules will enable us to rate cables in a correct way. Instead of dealing with volt drop they will deal with temperature rise. It is interesting to learn that small cables laid in casing are only able to deal with smaller current densities. The next gradation is cables laid in steel piping, and then cables able to stand highest current densities are those laid directly in plaster. I think it would be of very great interest and help if we could even further trespass upon the National Physical Laboratory. I hope that some day they will be able to make a further investigation on the lines of Fig. 17, that is to say, to deal with cables laid not within premises, but actually in the streets. The curve, as shown, at any rate gives us a very valuable indication of the lines on which we should proceed in distributing systems, because we see that cables laid in earthenware pipes carry a particular current with 20° rise; cables laid in bitumen, as the authors pointed out, for the same current, have only 13° rise, and when laid direct in the earth—wet earth in this case —there is only an 8° rise. That is a useful indication in cases where we want occasionally to run high density currents in distribution systems for a short time each day, as it points to the fact that, if other

things permit, lead-covered cables laid in soil are capable of higher densities than cables either laid solid or laid in ducts. Many of us have to lay cables in concrete or stoneware casings, and often have to run high density currents, so that it would be a very valuable contribution to our present somewhat limited knowledge if the authors could pursue this interesting and most valuable work of theirs into that region, and tell those of us who do not know, except on the occasion of breakdowns, to what limits we can go. If they could give us indications of the permissible current densities in three-core paper-covered cables, laid singly, and also in nests, following out the lines which Mr. Ferguson* reported at the St. Louis International Electrical Congress, I think it would be a very valuable contribution to our present knowledge. The authors do not deal specifically with the effect of these current densities and temperature rises upon the dielectrics used. I think that in paper-covered cables the insulation resistance drops some 4° with each °F. rise of temperature. It would help us very much to see what effect there is on the depreciation of dielectrics of different kinds when running cables at particular temperatures. Mr. Snell.

Mr. W. R. Rawlings: I think the paper we have before us is a text-book of the Wiring Rules if read in conjunction with the table which is to be found at the end of that book, and as a text-book it is really beyond criticism. I have read the paper with care, and I also have had the pleasure of seeing some of the tests carried out, and having done so I will caution any one who wishes to criticise the authors' work to be very careful, because at the National Physical Laboratory they carry out their tests with very great care, leaving nothing to chance. The cables were tested in a scientific manner, under practical conditions, and I think this is the only work of its kind which has been published. There is one very important factor brought to light by the authors, viz., that it is no longer necessary to follow the old Thomson law of 1,000 amperes per square inch. The old rule has permeated the industry to such an extent that it has blocked progress, and I was glad to learn from Mr. Sparks his views upon this important point. I am pleased to inform him that, as a contractor, I think he has done even more for us than he has done for the supply station engineer. We shall sell, perhaps, fewer large cables, but I hope, and venture to suggest, that we shall sell ten times the number of small wires. Take a case in point: I have calculated that, where it would have cost £100 to lay down a small heating installation, it can now be done under £30, which must bring about business. This paper, in conjunction with the Wiring Rules, will do much to bring about that desirable day load, and a further demand for small heating apparatus, etc. Mr. Rawlings.

Professor A. W. Porter: Mr. Melsom referred to a small experiment of mine, showing the anomalous effect in the lagging of a wire. I showed the identical experiment eight years ago, and I believe it has been seen since by a very large number of engineers. What rather surprises me is that it has not apparently been known to the members of the Professor Porter.

* *Transactions of the International Electrical Congress*, St. Louis, vol 2, p. 666, 1904.

Professor Porter.

Wiring Committee. So far as I have read Mr. Melsom's paper, there are many things in that paper which I could not have predicted accurately from the experiments I have made myself up to date; but I think that, in the rough, one might have predicted the results which Mr. Melsom has obtained, several years ago. They fit in exactly, as far as I can see, with what our expectations would have been, taking into account all the circumstances of the various cases. However, it is exceedingly important to have points like these verified experimentally, accurately, and in detail. We cannot always rely upon theoretical conclusions apart from experimental verification.

Mr. Whalley.

Mr. A. WHALLEY: Might I ask a question? In one or two of the tables references are made to paper-insulated concentric cables. If the inner and outer leads refer to the same cable, are the temperature differences for the same difference of resistance between outer and inner for all sizes, usually 4 per cent.? I judge by the omission from the paper of reference to lead-covered rubber cables that possibly no experiments were made with them. But if any were made, might I ask if the results attained were practically identical with the lead-covered paper cables? The same remark would apply to armoured cables. Lead-covered rubber cables, I apprehend, are chiefly of interest in connection with the wiring of ships. If a new scale of current densities has been adopted in the new Wiring Rules, would it be possible to add a curve "*y*" to Figs. 8 and 9, that we may be able to compare the new edition of the Wiring Rules with the tests recorded in this paper, and thus save each of us having to draw out the new curve, which I shall call "*y*," upon the curves in this paper? Perhaps the new formula given in Table III. may ultimately reach us in rather a simpler form. It contains in the ratio D/R a value D which cannot be determined accurately until the cable is selected.

Communicated: Having obtained a copy of the new Wiring Rules (the stock was temporarily exhausted at the time the paper was read) I see that the "reference" of this matter to the National Physical Laboratory by the Wiring Committee practically asked for an interpretation of the 1907 temperature limits adopted by the Institution of Electrical Engineers, and an interpretation has been given, in a most capable manner, but without the expression of any opinion upon these temperature limits or a maximum air temperature of 100° F. being assumed for every installation. The Wiring Committee appear to have adopted the National Physical Laboratory figures before submitting them to the members of the Institution. In connection with the present paper, therefore, a discussion of the new rules is not possible, as the National Physical Laboratory and the authors have done all they were asked to do. On plotting curves of current and section between 0·25 and 1·00 sq. in., we have a straight line for paper and fibre cables, but for rubber cables the line is hollow, the greatest depression being at 0·5 sq. in. and for about 15 amperes. Is this intentional? It would be interesting to know whether vulcanised bitumen cables come under the rubber limits and also how aluminium cables are

to be treated. While under all preceding rules paper and rubber cables have been on the same footing, now this is only so for small sizes. For both alike the current is at the rate of 4,000 amperes per square inch up to $\frac{7}{18}$ for paper and $\frac{7}{17}$ for rubber, but for larger sizes a paper cable is allowed to carry roughly 60 per cent. more current than a rubber cable of the same section; or for the same current a rubber cable has to be roughly twice the section of a paper cable. This change is most drastic, and seems excessive, considering the vast majority of all installations must have a maximum air temperature considerably below the 100° F. assumed, and that there has been no change in the working conditions under which rubber cables are used. Mr. Whalley.

Mr. C. C. PATERSON: Mr. Sparks indicated that the new table and new values were especially applicable to power circuits, indicating that the question of voltage drop on the line does not come in to the same extent as for wiring lighting circuits. It is a fact, however, that, even under the new rules with the largely increased limit of current density in small wires we are no worse off from the point of view of voltage drop in lighting circuits than we were under the old tables when carbon filament lamps were exclusively in vogue. The candle-power of metallic filament lamps varies, with voltage fluctuations, only about half the amount that it does in carbon lamps. Hence twice the current density is permissible in leads to tungsten lamps as compared with carbon filament lamps. This appears to me to be the chief justification for the general use of the new table for lighting installations. Mr. Paterson.

Mr. T. E. RITCHIE: The paper bristles with points of interest, some of which are large and some small. One of the minor ones is the reference made by the authors to the question of the grooves in casing. It has, in practice, been considered by quite a number of people an advantage to have the grooves somewhat larger than necessary rather than quite a close fit, and this the authors have conclusively demonstrated to be incorrect. Then as regards the question of the influence of the increase in the rating of the smaller cables in connection with their use for electro motors, as referred to by one of the previous speakers, I can assure you that the effect of this, or any alteration tending to reduce the cost of installation, upon the motor industry will be immediate and, I think, pronounced. Mr. Paterson has touched upon a point which I had in my mind in the matter of lighting work, but he has, in stating that he cannot conceive an installation being wired for anything other than metallic filament incandescent lamps, probably inadvertently overlooked an illuminant which the increased current densities now permissible will affect very materially and very advantageously, and that is the arc lamp. In arc-lamp work there is not, as a rule, any difficulty in allowing for quite a considerable drop in pressure. We have, unfortunately, to dissipate that in most cases whether we like it or not, and so shall not usually have any difficulty in running up to the full limits of the new carrying Mr. Ritchie.

Mr. Ritchie. capacities, and in this way taking the fullest advantage of the improved conditions. A further advantage is that by absorbing most of the surplus voltage in the conductors the heat due to the absorption of the excess wattage is dissipated evenly over the whole of the network, instead of being concentrated in the steadying or line resistance, with the result that either the size and cost of the latter can be reduced or the apparatus as a whole rendered considerably cooler. As instancing the practical application of this point I have taken the opportunity, in the short time which has elapsed since my receipt of the paper and our meeting this evening, of running over the cost of the cables used in a large arc lamp installation in a locomotive works, where the wiring, of which I had retained particulars, ran into a considerable sum. I carefully compared what was then necessary in the way of wires and cables, and what it cost, with what would have been necessary had the present rules been then in force, with the result that I found that under the new conditions a saving to the purchasers could have been made representing approximately 17 per cent. upon the capital outlay for the entire installation, an item which even the wealthiest of us cannot afford to ignore, and one which has a very great practical bearing upon the matter from the point of view of the user, the manufacturer of the arc lamps, and the supply station engineer.

Referring now to quite another matter, I should like to ask the authors whether they have carried out any investigations upon, or have definitely considered at all the question of pit shaft cables. In such cases the conditions differ quite materially from any of those given in the curve, Fig. 17. There is in very many pit shafts a dampness or moisture which amounts very often to pronounced wetness, and there are also very unusual conditions in the way of something allied to a forced draught, and as, moreover, it is necessary to take whatever electrical energy may be required in the pit down the one or two cables which are usually available, the maximum rating at which the same can be worked becomes a matter of very great importance to colliery proprietors and to those called upon to devise installations for them and to advise them upon such matters. If, therefore, the authors could, before the paper is definitely concluded and printed, give us even some approximate information upon this point it would be of interest to all and of material value to many of us.

Mr. Digby. Mr. W. P. Digby: As against the remark of a previous speaker with regard to temperature limit for paper-covered cables, I should like to point out that, as Mr. Whalley stated, there is a large fall in insulation resistance, both with the mineral and vegetable oils, but, on the other hand, there is an increase in dielectric strength on raising the temperature, which would offset some of the effects due to the fall in insulation resistance.

Dr. Russell. Dr. A. Russell (*communicated*): The authors' paper is both timely and interesting, and their experimental results are suggestive. The theory they give of the cooling of cables could, however, be considerably improved by taking into account the important results recently

Dr. Russell.

obtained by the great French physicist, Boussinesq. In explaining, for example, why it is that putting an insulating covering round a cylindrical wire sometimes permits a higher current density for a given temperature rise, they have, following Fourier, assumed that the "external conducibility" h may be regarded as approximately constant. Their own numerical results prove that this assumption cannot be made. It will be of interest, therefore, to indicate a more rigorous method of proof and to give an historical *résumé* of the problem. So far as I can ascertain, the first account of the cooling effect produced in certain cases by an insulating covering was given by Lord Kelvin to the Royal Society of Edinburgh on March 23, 1884. The paper was entitled "On the Efficiency of Clothing for Maintaining Temperature," but it was never published in full, and only the briefest abstract appears in *Nature*.* A letter, however, from Dr. J. T. Bottomley † which appears in the *Electrician* for April 19, 1884, enables us to reconstruct Kelvin's theorems. Apparently he solved by Fourier's method the problems of a covered sphere and a covered cylinder cooling in air. For the case of a sphere, using the ordinary notation, we have, when the flow is steady—

$$-4\pi r^2 k . \partial\theta/\partial r = \mathrm{H},$$

where H is the heat generated per second in the sphere. Hence, since H is supposed to be constant, we get—

$$\theta - \theta_1 = \frac{\mathrm{H}}{4\pi k}\left(\frac{1}{a} - \frac{1}{b}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where θ is the temperature of the sphere, θ_1 the temperature of the outside of the covering, a the radius of the sphere, and b the outer radius of the covering. Apparently Lord Kelvin made the assumption that h was independent of the curvature, and hence—

$$\mathrm{H} = 4\pi b^2 h(\theta_1 - \theta_0),$$

where θ_0 is the temperature of the air before it reaches the sphere. Therefore, by (1)—

$$\begin{aligned}\theta &= \theta_0 + \frac{\mathrm{H}}{4\pi}\left(\frac{1}{h b^2} - \frac{1}{k b} + \frac{1}{k a}\right)\\ &= \theta_0 + \frac{\mathrm{H}}{4\pi}\left[\frac{1}{h}\left(\frac{1}{b} - \frac{h}{2k}\right)^2 + \frac{1}{k a} - \frac{h}{4k^2}\right].\end{aligned}$$

When H and a are constant and b varies, we see at once that θ has its minimum value when ‡ $b = 2k/h$. Hence, if a is less than $2k/h$, putting a thin covering on the sphere will cool it. Similarly we can show that for a cylinder the critical value of the radius is k/h. An independent proof of this result was also given by Professor G. Forbes (reference cited by authors). Little value, however, can be attached to these results. Dr. Bottomley, and presumably also Lord Kelvin, were not

* *Nature*, vol. 29, p. 567, 1884. † *Electrician*, vol. 12, p. 541, 1884.

‡ In *Nature* and in Dr. Bottomley's letter this is written $k/(2h)$.

Dr. Russell. satisfied that the assumption that h is constant is legitimate. The former points out that if we make this assumption we are led to the conclusion that the current carried by a wire for a given temperature rise varies as $D^{3/2}$, a result which both he and Professor Forbes proved experimentally to be wrong. The latter * published his results as far back as 1882. In theoretical work, therefore, the constancy of h should not be assumed.

In 1901 † Boussinesq obtained a solution for the cooling of a strip of metal by a stream of fluid. He has since extended his solutions to the case of cylinders, spheres, etc., and has also given strong theoretical reasons for concluding that Newton's law of cooling, which Newton deduced from experiments on convective cooling, was true to a high degree of accuracy. Mitchell, Compan, and others have proved that Newton's law is true even up to differences of temperature as high as 200° and 300° C. The known values ‡ of Stefan's constant for radiation prove that the radiation loss is generally only a small fraction of the loss due to convection currents. Hence in a recent paper § to the Physical Society I have obtained approximate solutions of various practical problems by neglecting altogether the radiation losses. It is proved, for example, that the current required to raise a bare cylindrical wire to a given temperature varies as $D^{1 \cdot 25}$. The experimental results obtained by Forbes in 1882, using a tangent galvanometer as an ammeter, agree with this law within the limits of experimental error. Schwartz ‖ found experimentally in 1905 that it was very approximately true. The mathematician can take the radiation losses into account without much difficulty, but the higher accuracy of the formulæ obtained hardly compensates for their increased complexity. For the cooling of an insulated cylinder in a stream of liquid I have (*l.c. ante*) given the following solution :—

$$\theta = \theta_0 + \mathrm{H}\left(\frac{\sqrt{\pi}}{4\sqrt{2 s \sigma k_1 \mathrm{V D}}} + \frac{1}{2 \pi k} \log \frac{\mathrm{D}}{d}\right),$$

where s is the specific heat, σ the density, k_1 the thermal conductivity, and V the velocity of the fluid in which the cylinder is immersed. The critical value of D is $\pi^3 k^2/(32\, s\, \sigma\, k_1 \mathrm{V})$. For given values of θ and θ_0, H varies inversely as the quantity inside the brackets, and so I should not expect that the current density can in the general case be given by a formula of the type $i = k\,(\mathrm{D/S})^n$.

An approximate solution of Lord Kelvin's problem of a covered sphere cooled by a current of fluid can be found as follows. Boussinesq ¶ has shown that for a sphere—

$$\mathrm{H} = 4 \pi b^2 \sqrt{\frac{2 s \sigma k_1 \mathrm{V}}{\pi b}}\,(\theta_1 - \theta_0).$$

* *Electrician*, vol. 9, p. 497, October 7, 1882. † *Comptes Rendus*, 133, p. 257, 1901.
‡ *Journal de Physique*, 9, pp. 468–490, 1909.
§ *Philosophical Magazine*, vol. 20, p. 591, 1910.
‖ *Journal of the Institution of Electrical Engineers*, vol. 35, p. 364, 1905.
¶ *Comptes Rendus de l'Academie des Sciences*, vol. 138, p. 1191, 105.

Hence, by (1)— Dr. Russell.

$$\theta = \theta_0 + \frac{H}{4\pi}\left(\frac{\sqrt{\pi}}{b^{3/2}\sqrt{2 s \sigma k_1 V}} - \frac{1}{k b} + \frac{1}{k a}\right)$$

Therefore θ is a minimum when—

$$b = 9\pi k^2/8 s \sigma k_1 V.$$

We see that, in some cases, clothing a body keeps it cool, and in other cases, keeps it warm. This result is fairly well known to physicists, but a rigorous proof does not seem to have been hitherto given. Fourier, in his "Theory of Heat," points out that his coefficient h must depend on the velocity of the fluid in which the cooling body is immersed, as well as on the density and the capacity of heat of the fluid. He also points out that by destroying the polish of the surface or blackening it the value of h is considerably increased. It would be of interest to know whether making the surface of the lead sheathing rough or painting it black would have the greater effect in keeping the cable cool. Other things being equal I should expect that making it rough would be the more effective. In the recent experiments carried out by David * it is shown how the temperatures of the sheath and the core vary as the current is increased. The effect on both of blackening the sheath is also shown, but further experiments are desirable.

Mr. C. BEAVER (*communicated*): While in the opinion of some it may be undesirable to have increased the maximum current density on the smaller conductors in the 1911 Wiring Rules, the broad advantage of having the figures put on a consistent basis is undoubted. It has always been a matter of some surprise to me that while the tables deal with single cables up to 1 sq. in., they ignore twin, concentric, and multicore cables in which maximum current densities will be decidedly lower for a given temperature rise. These cables are far more likely to come into a wiring job, say, for a mill or factory, than 1 sq. in. single cables. In fact, one might almost go further and say that when large cables are used they are quite likely to be laid underground by methods which will further affect the permissible current density. The authors state that the heating of buried cables is outside the scope of their paper, and that they are not aware of any attempts being made by engineers to determine the temperature rise in cables as laid. As one who has had considerable experience in this branch of the subject, and conducted a wide series of experiments on it during the past four years, I would point out that it is not quite so easy as the authors infer to conduct heating tests on cables *in situ* unless specially laid for the purpose, the difficulty being to accurately determine initial temperatures. I notice that the authors do not state what the actual range of initial temperature was in their experiments, and would point out that to a considerable extent the initial temperature determines the temperature rise, because the final steady temperature depends on the Mr. Beaver

* *Bulletin de la Société Internationale des Électriciens*, vol. 10, p. 511, 1910.

Mr. Beaver. heat dissipation conditions, and is for a given set of conditions of current density and heat dissipation almost constant, at least within a few degrees. The following initial and final temperature figures, taken on 0·1 sq. in. 20,000-volt paper-insulated, lead-covered, 3-core cables, running at a current density of 2,000 amperes per square inch illustrate this. They are taken at random from a mass of results, and represent the hottest and coolest systems of underground laying respectively.

Laid Solid in Wood Troughing.		Armoured and Laid Direct.	
Initial Temperature.	Final Temperature.	Initial Temperature.	Final Temperature.
74·0° F.	146·2° F.	60·3° F.	135·6° F.
47·5° F.	140·7° F.	50·5° F.	131·0° F.
42·5° F.	143·0° F.	—	—

It will be seen from these figures that unless the initial temperatures were either kept constant or allowed for, it would be misleading to quote figures of temperature rise. With regard to the authors' assumption that the temperature of the cable was the same as that of the surrounding air, I have not found it sufficiently accurate in the case of medium and large cables to take either air temperatures for cables above ground or ground temperatures for buried cables. I have therefore always determined the initial temperature by reference to the resistance figure obtained after immersing the whole cable in water at constant temperatures for 48 hours before laying or fixing.

There are one or two observations made by the authors which, while true for the conditions considered by them, do not by any means hold good for buried cables. Not only does the method of laying introduce a variation, but higher temperature rises than those considered by the authors (which are often used in practice) make the variations still more marked. I refer to the remarks in the paper as to there being very little difference between rubber- and paper-insulated cables when laid under similar conditions, and also as to there being only a small difference between rubber cable in casing and in iron tubes in air. A glance at Fig. A will show that when laid solid, the temperature rise on a rubber cable may be about 20° F. higher than on paper lead-covered cable. The difference between rubber cable in casing and in iron conduit slung on a wall in air is about 45° F. It should, however, be mentioned that the casing did not closely fit the cable. In my experiments I have found that for certain ranges of time before a final steady temperature is reached, and particularly where dissipation of heat is chiefly effected by radiation or convection and not by conduction, the effect of *reflection* of heat from the interior of a lead sheath is quite marked, and has an appreciable accelerating effect on the

rate of heating. This may sometimes be of importance to a station engineer in connection with intermittent or peak loads. The shape of some of the curves in the diagram illustrates the point to some extent. Mr. Beaver.

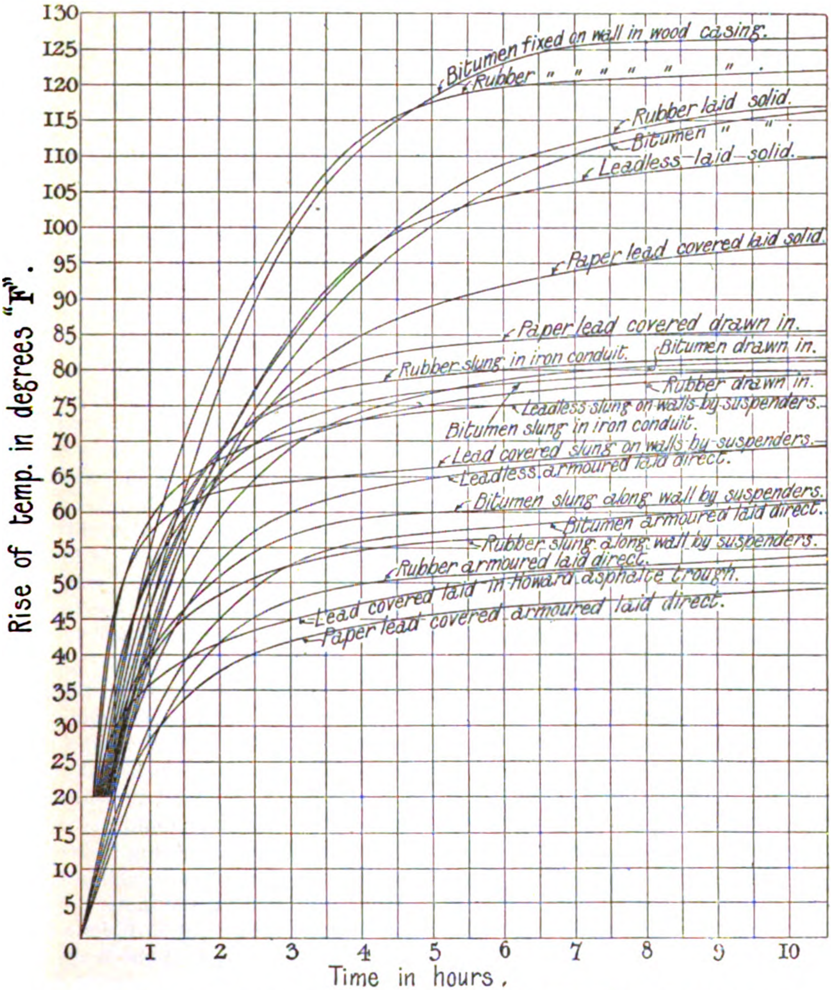


FIG. A.—0·5 sq. in. Single Cables of four different Types laid in various ways.
C.D. 1,500 amperes per square inch.

With regard to conduction, while it is obviously the best means of dissipating the heat of a cable, a good deal depends on the medium. This point is well illustrated in the diagram by comparison of the

Mr Beaver. curves shown for paper lead-covered laid solid, *i.e.*, in wooden troughs filled with bitumen, and the same cable laid in Howard asphalt trough, the latter running nearly as cool as when armoured and laid direct. Many other more or less unexpected results occur when other variants such as extra high-tension thicknesses of insulation, different types and constructions of cable, high-current densities, multiple conduits, combinations of materials, etc., enter into consideration, and it is therefore perhaps excusable to emphasise in some detail the authors' statements as to the limits of the application of their most valuable conclusions.

Dr. Glazebrook. Dr. R. T. GLAZEBROOK: Before calling upon Mr. Melsom to reply, I wish to thank the Institution very sincerely for the way in which this paper has been received and for the remarks which have been made as to the work of the National Physical Laboratory in connection with it. I am not sure that it is entirely fitting that I should be, by an accident, occupying this chair this evening. The President and Vice-President were called away by duty to attend a more festive gathering, and the Secretary told me in the Council meeting that it was my duty to be present here and to take the chair. It has been a great pleasure to me to listen to what has been said about the work of the laboratory, and about this paper by Mr. Melsom in particular. I also value the opportunity of assuring the Institution of the readiness with which the work was undertaken by the Committee of the Laboratory when I placed the matter before them, and of the indebtedness that we feel at the Laboratory to the cable-makers and to the Wiring Rules Committee who have put it in our power to carry through a piece of work which I believe is of real value. It is only another instance of the way in which manufacturers, when once they realise that an investigation is of importance for their work, are always ready to come forward and help with material and suggestions in a manner which they alone can do. I wish, too, on behalf of the Institution to thank the Wiring Rules Committee for the work which they have carried through. The meeting to-night will have realised that the labour connected with the issue of this new edition of the Wiring Rules has been no light task, and the Institution as a whole and all its members are, I feel sure, very much indebted to Mr. Sparks and the other members of the Committee for the time and trouble they have taken in bringing these Wiring Rules to their present condition, and in conferring on the industry such great benefits as it is clear will accrue from the issue of the new rules. Suggestions have been made for still further work in this direction; and if that work can go on with the cordial co-operation of the Institution and with the assistance of the manufacturers in providing the necessary material, we shall be glad to continue it at the Laboratory.

Mr. Melsom. Mr. MELSOM (*in reply*): I think the first thing I have to remark on is the point raised by Mr. Snell with regard to buried cables. It is correct to assume that cables which are buried in the soil can be run at a higher current density than when in air. It should be mentioned, however, that the soil in which the cables were laid was wet, and this,

of course, affects the cooling considerably. I do not know what the conditions are in other places, but in the Thames Valley the soil 4 ft. down is probably never dry. With regard to the effect of temperature rise on the insulation resistance, we have made tests of the change of insulation resistance with temperature and find that the decrease is more nearly 50 per cent. for a rise of temperature of 1° C., the cable tested having an insulation resistance of several thousand megohms at 0° C., and of less than 1 megohm at 100° C. In answer to Mr. Whalley, the paper cables were—the outer as well as the inner lead—insulated, otherwise there would have been a difference in the sectional area of the outer conductor owing to the lead covering carrying a portion of the current. The authors did not experiment with lead-covered, rubber-insulated cables ; but it seems obvious that they would not differ very much from rubber-insulated compounded cables. Mr. Melsom.

In reply to Mr. Ritchie, we did not especially consider the question of cables as used in colliery shafts, but perhaps the results given in curve 4, Fig. 17, might give an indication of the results that may be expected. In this case the cables were laid in a shaft, through which a current of air was drawn, and from a comparison of curves 1 and 4, Fig. 17, it will be seen that under these conditions the cable required about 50 per cent. more current to raise it to a given temperature than when it is laid in still air.

(*Communicated*) : Since this paper was written the authors have seen an experiment shown by Professor Porter at the Royal Society's conversazione by which the apparently anomalous effect of the lagging under certain conditions assisting instead of retarding the dissipation of heat developed in the conductor is clearly shown. The experiment consisted of a thin platinum wire heated by a current. At intervals along the length of the wire pieces of glass tube were sealed on, the difference of temperature between the portions of the wire inside and outside the glass tube being clearly visible. This experiment was first shown by Professor Porter some eight years ago, and was exhibited before the Physical Society on November 13, 1908.* Dr. Russell in his paper on "The Convection of Heat from a Body cooled by a Stream of Fluid," † mentions the same experiment, but with the substitution of a manganin for a platinum wire. The authors have, however, taken the opportunity of determining under practical conditions the thermal constants of certain cables, the coverings of which consist of successive layers of various materials which presumably differ considerably among themselves in their thermal properties. By means of the constants so obtained we have set out the effect of various thicknesses of covering in promoting the dissipation of heat from the conductor. This is shown in Fig. 14, which illustrates the special aspect of the effect with which we are here concerned, that is, as it affects the current density that produces a given temperature rise. Each of the

* *Philosophical Magazine*, vol. 20. p. 511, 1910.
† *Proceedings of the Physical Society*, vol. 22, p. 432, 1910.

Mr. Melsom. curves shows for a stated size of conductor the effect upon the permissible current density that results from varying the thickness of the insulating cover.

In this connection, Dr. Russell's remarks on the variation in the value of the "external conductivity" h for different cable sizes is of considerable interest. In the absence of the more elaborate investigation which would be necessary in order to determine experimentally the exact nature and amount of this variation, it is impossible to say how far the curves shown in Fig. 14 would be affected by taking this variation into account as a more exact theory of the heat dissipation of lagged cables would require. Dr. Russell alludes to our numerical values of h as showing this difference for different sizes of external diameter of cable covering; but even if we regard this difference as solely due to the "curvature effect," and leave aside the possibility of its arising even in part from difference in the surface condition of the cable, it does not appear that by taking account of this variation in setting out the curves in Fig. 14 their general character would be substantially altered, and it was to their general character that we desired to call attention. With reference to Dr. Russell's objection to the formula—

$$i = K\left(\frac{D}{S}\right)^n$$

we, of course, quite agree that such a formula does not meet the requirements of a general mathematical theory of the heating of lagged cables. This, however, it was not intended to do, but to resume in simple mathematical form the behaviour of commercial cables under ordinary working conditions and having some such thickness of insulation and covering as would occur in practice. Its use in interpolating between any two not too widely separated cases of actual observation is, we think, sufficiently well justified by the graphs in Figs. 11 and 12. The authors are much indebted to Dr. Russell for his remarks and suggestions on the theoretical aspect of the subject, and desire to thank him for this and the references which he has so kindly given them.

With regard to Mr. Whalley's remarks, since the paper was read the authors find that the table stating the current density in each size of cable when run at its maximum permissible current has been omitted from the new tables. The authors are hoping to commence shortly an investigation which will enable them to express an opinion as to the safe temperature limits at which cables may be run.

Mr. Beaver's remarks seem to deal with work which has been omitted rather than with the work that has been done, and in so far the authors must agree with him. There is a great deal of work to be done in order to determine the heating in cables of various types, twin, concentric, and multicore, when laid underground and under the various conditions at present in practice. It is stated in the paper that the question of buried cables was "outside the scope of the present paper." As a matter of fact, the authors are at present getting out a scheme of

work for submission to the Wiring Rules Committee, which will include an investigation into these questions. With regard to carrying out tests *in situ*, it is, of course, not at any time possible to make very accurate tests under these conditions unless the cables are laid with this end in view. In stating, however, that the tests could be easily made, the authors had in mind more than one cable system of which one of them had practical experience, in which had very slight modifications been made when the cables were laid it would not have been difficult to have obtained a very fair approximation of the extent of the heating. Mr. Beaver's remarks about the initial temperature do not seem to be borne out by his figures, as his table shows that even with a large variation in the initial temperature the final temperature in each case is nearly the same. The temperature of the surrounding medium must, of course, always be allowed for in determining the rise of temperature. It will, however, probably be found that the temperature of the soil a few feet down is fairly consistent for days together. Mr. Beaver's tests of cables in air have no doubt been carried out in a rapidly fluctuating temperature, and in this case the cables would not follow the variations of air temperature. In the case of the experiments made by the authors the room temperature was nearly constant, any variations being very slow. It was not assumed but was found by experiment that under these conditions the cables followed the air temperature very closely. **Mr. Melsom.**

On the motion of the chairman, the authors were heartily thanked for the paper.

A POWER COMPANY'S TESTING DEPARTMENT.

By E. FAWSSETT, Associate Member.

(*Paper received March* 4, 1911. *Abstract of Paper and discussion read before the* NEWCASTLE LOCAL SECTION, *April* 10, 1911.)

In these few remarks I propose dealing with (1) the scope of such a department, (2) the equipment recommended, (3) clerical work, (4) arrangement of staff, (5) plant testing, and (6) notes in general, and specially in connection with polyphase meters.

Scope.—The scope of the testing department of a large electricity supply undertaking is considerably modified from that of a small concern where every description of such work is best centralised in the one department. In a larger business the testing department becomes more of a referee for others.

The chief routine work of the department is to maintain the accuracy of all the consumers' meters, and in the general lay-out and staffing one must bear that in mind.

It is obvious that the revenue of the undertaking is directly dependent on the average accuracy of the meters. One per cent. here is of much greater value than in works cost or distribution efficiency.

Equipment.—In considering the arrangement of the department, the frequency of examination of the supply meters must be settled, whence can be estimated the number of each class to be dealt with per annum.

A large power meter will call for more attention than one used in office lighting on the score of revenue, although the design of the former may be more satisfactory. It is usually best to change all small meters periodically and to examine the larger ones in position, as not only are the facilities for doing so improved, but the objections to changing are greater. The cost of testing a large power meter in position is much less than the cost of changing and interest on replacement stock, besides which the meter is tested on its actual load and the continuity of the readings is not interfered with.

One room will be set apart as a commercial laboratory, where the various standards are set up and arrangements made for readily checking sub-standards against them. These standards would not be employed outside, with the possible exception of the potentiometer, which lends tself to plant testing and such like on reasonably steady loads far more readily than is generally supposed,

and is often quite the most satisfactory instrument in such cases, in which it is always advisable to limit the instrument connections as far as possible, for the ready understanding and agreement of all parties concerned. The standards should be such as can be simply checked for accuracy of adjustment at any time, and should command universal acceptance. While new instruments of this class are continually being produced, such should not be looked upon too favourably for this work, seeing that the instruments adopted must satisfy all comers. Direct reference to standard cell and standard resistance should be aimed at.

The sub-standards will be portable, for use all over the system, and should be rendered fool-proof as far as possible. A definite rule should be made as to the frequency of the comparisons with the primaries, otherwise this is very apt to get neglected.

For test-room work an extremely convenient arrangement is one in which the shunts are all permanently brazed together in series, the millivoltmeter being also permanently connected across the whole, connection to the circuit being made by a multi-way switch at the range desired. This helps very much to prevent any laziness in changing ranges for different loads, and so obviates readings being taken too low down the scale. As an additional preventive, all the intermediate divisions might be removed up to a quarter of the scale length. The ironless dynamometer-type " precision " instruments are excellent for alternate-current wattmeter work. The impedance and resistance of the pressure circuits of these wattmeters should be known in order to correct at very low power factors for the slight inductance necessarily present ; also care must be taken in connecting not to get errors due to electrostatic effects, by arranging that fixed and moving coils are at about the same potential.

A large number of subsidiary pieces of apparatus will be required to meet individual cases. One of the most interesting of these, and one that, on a large system at least, is thoroughly justified, is a complete oscillograph outfit. Recent advances in construction have now made it quite practicable to insert the vibrating mirror direct in the high-tension circuit, which does away with the distortions of current and pressure transformers. Long records of a disturbance can then be taken on a cinematograph film.

Polyphase meters are tested in a separate bay, and for this work and other alternating-current testing the ideal apparatus is two alternators driven from one motor, so arranged that the phase relationship of the two machines can be easily altered while running—this is effected by mounting one stator on a cradle so that it can be rotated relatively to the other one. Such an apparatus is somewhat expensive, but it is very well worth the outlay, being far more generally useful and satisfactory than a phase shifter of the static induction-motor type, which is affected by the nature and balance of load. In this latter case the heavy current may be obtained from transformers, but if so they must be built on the lines of power trans-

formers, reversed-current transformers give an exceedingly bad wave-form.

Most power companies also supply sufficient lighting to render accurate photometric tests necessary. A dark room for this is also convenient for the oscillograph work. It should certainly be provided with a primary standard of light. An aneroid and hygrometer will be needed, and then if proper attention is given to the ventilation there is no difficulty in the use of a gas standard. It is very important to prevent errors due to reflection, and to check frequently the balance of the photometer bench, as errors from various sources creep in unsuspected. The gas standard should only be used to check sub-standards, so that the lamp to be tested occupies the same position on the bench as the primary did.

Clerical Work.—This should be kept as simple as possible, and no books used. Each meter or piece of apparatus has a card, the whole of the records being kept on them, particulars on one side and tests on the other; the whole history of the apparatus is thus seen at a glance. The large meters that are tested frequently in position are treated in the same way. Special tests and reports are typed and filed as part of the general filing system.

Plant Testing.—The behaviour of most auxiliary apparatus is so affected by the amount of power behind it that a proper test can only be carried out in a specially equipped building, near to, but isolated from, the power station, with facilities for handling plant, absorbing large quantities of power and direct supply from a large generator unit if desired.

Polyphase Testing Outside.—In the case of polyphase tests the meter is always energised off current transformers, and is not connected direct to a circuit above 500 volts, so that it is perfectly simple to link a check meter in the secondary circuits, it being standard practice to protect the pressure wires to the meter by fuses easily drawn and sealed; any adjustments may, therefore, be effected in absolute safety, without any interruption of supply.

Polyphase Tests Generally.—Owing to phase-displacement—the small angle, usually less than 1·5°, by which the secondary current leads in front of the primary—it would seem to be necessary that all the meter tests be made on the transformers, which would be very inconvenient and expensive, in view of the large number of adjusting tests necessary. However, this is easily got over. The current transformers are checked for ratio, and quite approximately enough for phase angle, by using wattmeters instead of ammeters. One test is made at unity and one at zero power factor on the primary, with constant volts and amperes.

The wattmeter readings are as follows:—

P_1 Primary reading, unity power factor $= V\,A \cos 0° = V\,A$.

S_1 Secondary reading, unity power factor $= V\,a \cos (0° - \theta) = V\,a$ very nearly; (within $\frac{1}{2}$ per cent. if θ is 5°, θ usually being 1°.)

Hence—

$$\text{Ratio} = \frac{P_1}{S_1}.$$

P_2, Primary, zero power factor $= 0$.
S_2, Secondary $= V\,a \cos(90 - \theta)$.

$$\frac{S_2}{S_1} = \frac{V\,a \cos(90 - \theta)}{V\,a \cos(0 - \theta)} = \sin\theta \text{ for a small angle };$$

i.e., the ratio of the secondary readings gives sine of angle of phase displacement. If, then, θ is so found, the error due to it at any power

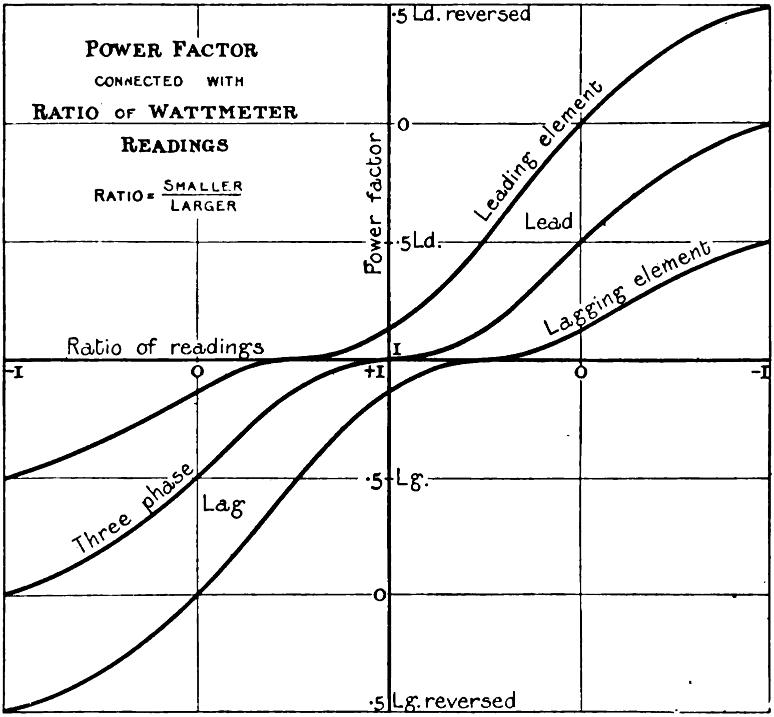


FIG. I.

factor is known, and when the meter is adjusted for power factor the necessary allowance is easily made.

An ordinary polyphase meter has two distinct elements on the two-wattmeter principle, and the necessary tests on such a meter are: (1) equality of torque on the two elements; (2) correct quadrature of power-factor adjustment on each; (3) compensation for friction at low loads; (4) correct speed for a given load and satisfactory curve.

In a recent paper before this Institution, figures were given show-

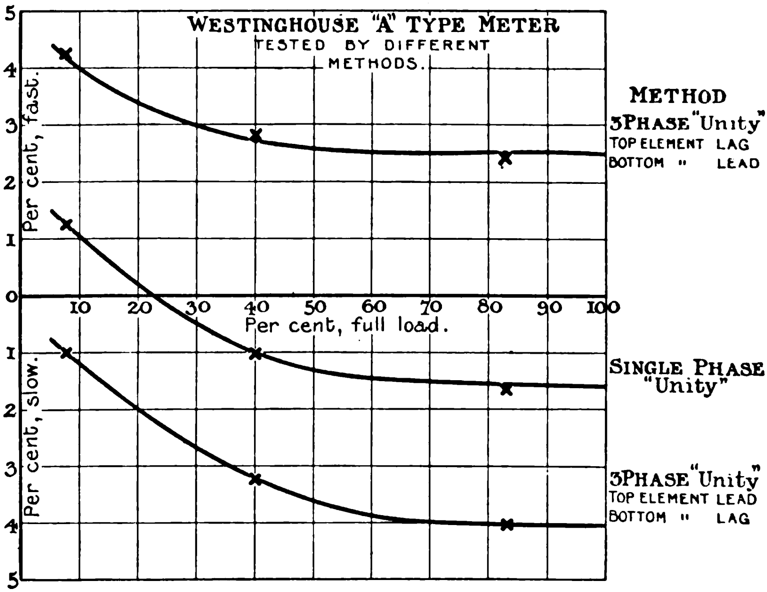


FIG. 2.

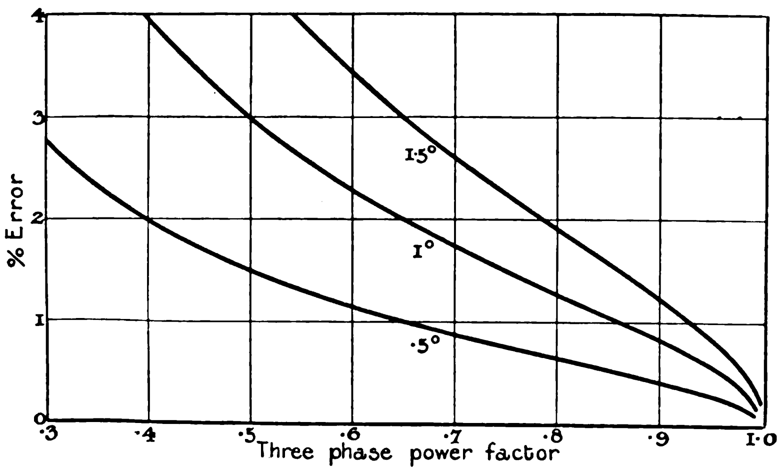


FIG. 3.—Polyphase Meters.

Three curves showing percentage error caused in precision wattmeters on secondaries of C.T.'s having various phase displacements.

ing that the two elements magnetically interfered with one another.* None of the tests given, however, showed what took place with the pressure coils connected correctly to the circuit, at 60° apart. The interference obtained under these conditions by the present author is much less than the figures given in the paper referred to, and refute the contention there expressed that a polyphase meter ought to be tested on single phase. It most certainly ought not, and the results on single phase will not give either a "mean" result or the performance of the meter on any polyphase connection (see Figs. 1, 2, and 3). As a result of these considerations, all polyphase meters should be tested on a polyphase circuit, and as the meter current seldom exceeds 5 amperes, this is easily done on a graduated lampboard, so arranged that the load on all three phases is kept balanced, thus obviating wave distortion or unbalanced pressures. To get the various power factors needed it is only necessary to cross-connect the current coils, as in Table I.

TABLE I.

Cross Connections in a 3-phase Circuit for Meter Testing.

Top element pressure between phases 3 and 2.
Bottom element pressure between phases 1 and 2.
3 reads highest on lagging power factor, with cyclic rotation, 1, 2, 3.

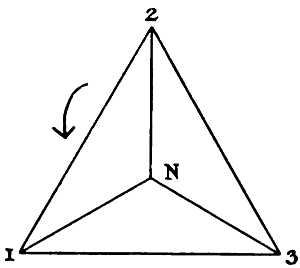


FIG. 4.

Current Coil Connections.

Element of Meter.	3-phase Power Factor.			Single-phase Power Factor.					
	0·5 Lead	Unity.	0·5 Lag.	0·5 Lag.	0·86 Lag.	Unity.	0·86 Lead.	0·5 Lead.	Zero. Lag.
Top ...	N–1	3–N	N–2	1–2	N–2	3–2	3–N	3–1	1–N
Bottom ...	N–2	1–N	N–3	1–3	1–N	1–2	N–2	3–2	N–3

* *Journal of the Institution of Electrical Engineers*, vol. 47, p. 46, 1911.

Mr. Cooper, of the N.E.S. Company's testing department, has designed a switch that does all that is necessary to obtain all these connections by one movement, and one is in very satisfactory operation now, and has reduced to about one-half the time necessary properly to carry out a complete cycle of tests.

Table II.

Interference tests between elements, using the above diagram to show connections to coils.

The current and pressure fluxes in one element are reversed as between each set of tests A and AA, and so on. The figure given for each test is the mean registration per cent. on 4 loads, unity power factor 100 per cent. and 50 per cent., 0·5 lag and 0·5 lead 50 per cent.

Mark.	A.	AA.	B.	BB.	C.	CC.	D.	DD.
Top Element—								
V	3–2	3–2	2–3	2–3	1–2	1–2	2–1	2–1
C	3–N	3–N	N–3	N–3	1–N	1–N	N–1	N–1
Bottom Element—								
V	1–2	2–1	2–1	1–2	3–2	2–3	2–3	3–2
C	1–N	N–1	N–1	1–N	3–N	N–3	N–3	3–N
Registration per cent.	100·6	100·3	100·9	100·9	101·4	101·3	101·6	101·3
Average ...	100·7				101·4			

Mark.		A.	A A.	B.	BB.
Registration per cent., with specified circuit broken. V_T = Topvolt coil. Full load	V_T	105·5	106·0	105·0	105·0
	C_T	103·0	102·2	102·2	102·0
	V_B	104·0	103·0	102·5	103·2
	C_B	101·7	100·5	101·0	101·2
		Bottom.	Top.	Bottom.	Top.
Registration per cent., with one element dead		105·1	106·1	104·7	106·8

Table II. shows the effect obtained on a set of tests for interference. Four tests were taken with each set of connections—viz., unity power factor 100 per cent. and 50 per cent. loads, 0·5 lag, and 0·5 lead 50 per cent. load. They agreed well between tests, and the mean registration for each set is given only.

Shortly, the results show that (*a*) with a definite phase connected to

an element, the maximum variation from the mean is, in each set of four possible cases, 0·4 per cent. for one phase, and 0·2 per cent. for the other; (*b*) the difference between the mean results of connecting phase 1 to an element and phase 3, 0·7 per cent. These are small errors compared with, say, the temperature error on an ampere-hour meter. If, however, closer accuracy is desired, all that is necessary is to mark the terminals of the meter for insertion in a particular phase, which has been standard practice with the Associated Companies on Tyneside and is the method adopted by the National Physical Laboratory.

The second part of the table shows the effect of breaking volt or current, or both, circuits of one element; this is only as a matter of interest (the pressure and current being in the correct phase relationship), but is not, of course, a case that occurs in actual practice.

Discussion before the Newcastle Local Section.

Mr. A. E. Moore: It is difficult to see how any power company making charges for the supply of electrical energy can be independent of the recognised authority. Any standards installed must have a known relation to the legal standards, and the legal standards are thus the only "primary" standards. A plug and bar type of switchboard is recommended as the best form. This depends very much on the current capacity of the circuits which it is intended to control, and also on the nature of the work carried out on the circuits. For a laboratory where a large variety of supply is required, and for currents not exceeding 50 amperes, a properly constructed plug- and bar-board is an extremely useful one. But in a meter test-room it is probably better and simpler to control each test bench with suitable switches and rheostats. It is not, as a rule, required to plug a high voltage or alternating current on to a meter bench used exclusively for testing direct-current ampere-hour meters, and why, therefore, make provision for it? The power factors obtained from 3-phase supply are only very approximate, and if the neutral point is used the wave-shape may be very different from that on the lines. It is stated that when current transformers are used to supply heavy currents (by using them reversed) it is necessary to know the shape of the wave. Suppose the shape of the wave so obtained is known, but is not what is required, what then? It seems to me much more important to know that the wave-shape is satisfactory, and this condition is generally obtained if suitable apparatus is employed and due precautions are observed. Instrument current transformers are not suitable for, and are not designed for the production of large currents in this way, and their use for this purpose is to be deprecated. I do not agree that it is sufficient to test meters of the induction type without their current transformers. Even if the ratio and phase-angle of the transformers are accurately determined, there is still the interacting effect between the volt fluxes and the current circuit. If the pressure coil of an Mr. Moore.

Mr. Moore. induction meter connected to a series transformer is excited, but the primary of the transformer left open, the meter creeps, and the amount of the creep apparently depends on the resistance and inductance of the secondary circuit. If the pressure coil be excited and the current coil be short-circuited the meter runs merrily. (Backwards, I think, but I am speaking from memory.) This effect cannot be taken into account if the meters are tested separately from their transformers. Moreover, why test separately? Why make three tests and a lot of calculations when the whole thing can be done more accurately and more satisfactorily in one test? It is stated that in determining the ratio "the secondary circuit should contain what it will have in practice"—neither more or less, I presume. It is rather difficult to see how this condition can be obtained, unless the equivalent of the series coil of the testing wattmeter is added to the circuit when in use. This, I think, is a still further argument in favour of testing meters with their series transformers.

With regard to the necessity for a phase adjuster for testing polyphase meters, there is equal necessity for one for testing single-phase meters when the two-circuit method is used. For steam consumption tests, very carefully standardised integrating wattmeters are probably more satisfactory than indicating wattmeters. It is open to question if such integrating wattmeters can be standardised with sufficient accuracy in position, as the load is hardly likely to be quite a steady one. The corrections obtained for the meters in the test-room—before and after the test—should be quite accurate if the conditions as to temperature, etc., are the same as those obtaining on the actual test, and provided the meters are fixed clear of stray magnetic fields, and are carefully handled in transit. In the case of converting or transforming machinery, if integrating meters are used on the one side, they should also be used on the other, and not integrating on the one and indicating on the other.

Mr. Ratcliffe. Mr. H. A. RATCLIFFE: Regarding the examination of meters on circuit, the best practice is to remove any meters suspected of being wrong, irrespective of size. I have no faith in the examination of meters on circuit, except in so far as may be necessary to discover some obviously mechanical fault which can be remedied without altering the calibration of the meter. Meters cannot be calibrated on circuit with any degree of accuracy, and it is questionable whether such calibration would be legally accepted. Meters should be changed as frequently as experience may show the work to be necessary, and financially justified by results, but constant tests on consumers' premises only cause the meters to be regarded with suspicion. The plug and bar type of switchboard is a survival of the early test-room days, and in some respects is very convenient for small test-rooms. My experience is that this type of board is not, as a rule, easily understood, and mistakes in connections are very easily made. For this reason it is an advantage to model the control arrangements more on the lines of standard station switchboards, and, where heavy currents are con-

Mr. Ratcliffe.

cerned, to dispense with cords and plugs as much as possible. The special requirements for the testing of polyphase meters in order to ensure accuracy on all loads and power factors are precisely the same as the requirements for single-phase meters. If a polyphase meter does not represent the equivalent of a combination of two or more single-phase meters, it cannot be regarded as a true polyphase meter. If a 3-phase meter is tested on a 3-phase circuit, assuming no interaction between the phases (a very unwarranted assumption), it is not possible to define the degree of accuracy closely unless the direction of the rotation of the phases is also stated. The use of current transformers reversed in order to obtain large currents for testing purposes is not permissible, and is a practice to be strictly avoided. The transformer is almost certain to be working with a high degree of saturation in the core, with the consequent production of a peaked or distorted wave. I cannot agree that it is sufficient to test polyphase meters without their current transformers, as experience shows that under no circumstances are the calibration results in perfect agreement with the results of direct tests in conjunction with the current transformers. The testing of transformer ratios with watt-meters instead of ammeters has certain advantages, but if the standard wattmeters are available for the ratio tests, and presumably also the necessary current supply, why not test the meters direct on the transformers?

I am glad to see that apparatus for mercury purifying is recommended, as the manufacturers charge a very high price for this work, and it is quite a simple matter to fit up apparatus which will practically be paid for by the saving on the first lot of mercury purified. It is necessary, however, to make quite sure that the mercury has been thoroughly purified (by no means a simple matter). Very careful drying is also necessary, and if done by the application of heat, care must be taken to avoid dangers due to vaporisation of the mercury. If by gas standard a flame standard is implied, I can endorse the remarks on photometric standards. I use a Harcourt 10-c.p. pentane lamp as a master standard, with most satisfactory results. Corrections for barometric and hygrometric effects are made in accordance with Paterson's formula. The great advantage of the flame standard is that the lamp itself is a mechanically reproducible standard, and it is a comparatively simple matter to ensure that the proper quality of pentane is used. The necessary chemical tests have been closely defined by the Metropolitan gas referees. A double alternator for alternating-current testing is very convenient, and probably constitutes an ideal piece of apparatus, but where such an expensive machine is not available, excellent results may be obtained with a phase-shifter; but it is necessary to use a type which does not distort the wave. The one described in the recent paper on "Electricity Meters" read before this Institution is a true auto-transformer and phase-shifter, and does not produce any distortion of the voltage wave.

As regards the clerical work, I most certainly cannot agree that

Mr. Ratcliffe.

books are not necessary. The various card systems may have their advantages for certain classes of work, but are not capable of universal application, and I consider a system of meter records without books would be, to say the least, scrappy and probably incomplete. I certainly fail to see what the storekeeper has to do with the history of a meter, and all tests and repair records should be confined to the meter department. It is not advisable for meters to be handled by a general storekeeper's staff. The potentiometer is essentially a laboratory instrument, and it should not be taken into the generating stations, etc., unless absolutely necessary. In the case of testing motor-generators and rotary converters, etc., a very common error is to use indicating instruments on, say, the direct-current side and integrating meters on the alternating-current side. This is entirely wrong, and the same type of instrument must be used on both the input and output sides of the machine. Integrating meters are essential for steam tests, and are probably also more reliable than indicating instruments for converter tests, but at the same time it is advisable to have the indicating instrument in circuit for taking checks of the actual conditions during the progress of the tests. I can thoroughly endorse the statements relating to the operating costs, and the justification for the existence of a testing department, the upper limit of $\frac{3}{4}$ per cent. of the total revenue as the cost of the testing department is probably rather on the high side.

Mr Maccall.

Mr. W. T. MACCALL: The chief point for discussion appears to be the question of testing 3-phase meters: whether they should be tested with their current transformers, and whether they should be tested on 3-phase or single-phase. I agree with Mr. Ratcliffe. It seems to me that if we have a current transformer as a working part of the instrument, instead of testing the current transformer and then the meter and adding the results together in order to get the final calibration, it would be much more satisfactory to test the two together, as the possibility of doubling the error is thus eliminated. With regard to testing on single- or 3-phase it certainly seems better to test the two elements separately on single-phase, as it is difficult to ensure that all the phases of a 3-phase circuit have exactly the same power factor. Further, unless the waves are pure sine waves we are not really getting what we think we are, since testing by using the neutral point brings in an extra error, owing to the well-known fact that if one has third harmonics in the phase waves these are cut out across the outers. The voltage of the neutral point would not be exactly as shown on the diagram, or rather the difficulty is to be certain that this is so, or in other words, that the neutral point is exactly in the centre of the triangle as shown in the diagram, and I think more accurate results are obtained by testing each one on single-phase and then adding the two results together. Of course there is the question of the error which is due to the inductance of the shunt. At a low power factor the percentage of error is large, but the error as a percentage of the whole load may not be so important; but even so I maintain that it is better to test each element separately rather than trust to the neutral

Mr. Maccall. point being in the centre of the triangle. Regarding test-room equipment I do not know from experience how the plug-board works in practice, but certainly the switchboard at Manchester is an exceedingly convenient one to work with, the regulation being effected by means of a number of resistances in parallel, there being separate resistances for $\frac{1}{10}$ amperes, 10 amperes, and 100 amperes; turning back the larger resistances to approximately the current required, then regulating the next step to suit, and so on, according to the size of meter being tested. The whole adjustment takes less than a minute and is exceedingly convenient. The card system is extremely good, but I think it should be supplemented by book-keeping to a certain extent, especially with a view to keeping notes for reference when considering new tenders, in order to compare results, as it is more convenient to have books to refer to than a collection of loose cards.

Mr. Holden. Mr. S. H. HOLDEN: Mr. Fawssett's paper is one of very great interest from the manufacturer's point of view as well as from that of the power supply engineer. Customers who have perfectly equipped testing departments such as the one at Newcastle are of very great assistance in giving data to the makers concerning the actual behaviour of their meters under working conditions, and thus enabling them to improve their methods and material. Such customers also furnish a most useful check upon the whole output of a manufactory, tending to keep every one up to the highest point of carefulness and accuracy. It is true that the imposition of these rigorous tests and conditions may cause worry and trouble, and at times makers are inclined to protest, but there is no doubt that it is largely owing to the stringent conditions imposed by the supply engineers that electricity meters have attained their present pitch of excellence, and I would far rather the conditions imposed were in the direction of greater rigour than less. In this connection I would like to mention the very good results accruing from the adoption of the Engineering Standards Committee Specification for consumers' meters; but already this is becoming a little out of date, and manufacturers are offering closer limits of error than are allowed by it. With regard to large meters of the shunted type, I think Mr. Fawssett has not mentioned one of their great advantages, viz., that the meters and shunts being standard the former may be removed for testing and even exchanged for another similar one without disturbing the shunt or the main connections at all. In testing polyphase meters I think that, if possible, the meters and transformers should be calibrated separately, but a final test of the two together under as nearly as possible actual working conditions should be made.

Mr. Longman. Mr. R. M. LONGMAN: The paper has covered considerably more ground in one respect than I anticipated, and yet it has not dealt with the things I wanted to hear about. With regard to the question of cleaning mercury, I have had a little trouble in this connection, which I attributed to failing to wash the mercury after the acid treatment, and thus leaving too much to the soda. Another point of great importance which has been mentioned is 3-phase against single-phase

Mr. Longman.

testing of polyphase meters. It appears to me that if we test on a 3-phase circuit without current transformers and make a full test of the transformers beforehand we eliminate any possibility of error. This method is perhaps better than testing single-phase with transformers. With regard to the question of wave-form in induction meters, Mr. Wild's paper, read before this Institution,* showed that the error was less than 1 per cent. even with very bad waves. In considering the testing of meters with their current transformers on any 3-phase circuit it is important to consider the question of the actual phase relationship, as in many cases there is not 120° between phases, and this may affect interaction between the elements. Mr. Holden has mentioned the question of manufacturers working in conjunction with the testing departments. I am very pleased to hear this, as it is most necessary. Some tests were made using one meter current transformer, ratio 40/5, inverted for generating the heavy current. A similar current transformer was in circuit connected to a meter, and a standard transformer was connected to a precision wattmeter. The actual power factor was obtained by ammeter, voltmeter, and wattmeter. With full-load current (40 amperes) passing the angle of advance of current was about 15°, with 25 amperes the angle was about 7°, and with 12 amperes only about 2°. This, of course, agrees with what the author's curves show. With the larger current the generator is more highly saturated, hence the phase displacement is considerable. When checking heavy-current meters the amperes and volts must always be taken so as to obtain the power factor of the test.

Mr. Fawssett has not touched upon the question of relay work, which really comes within the scope of the testing department, for if the relay department gets hung up they call in the testing department. If the current transformers have shunts across the primary winding the shunts take higher frequency currents. This explains why such different results are obtained on test to those obtained under actual working conditions, the generating current transformer used on test giving higher frequency currents of considerable magnitude. These differ as much as 50 per cent. owing to using a type of transformer for getting a large current which was hardly suitable. Regarding testing single-phase meters with current transformers, I would like to know what standards Mr. Fawssett advocates for measuring the true watts, and whether precision transformers with wattmeters are reliable. The oscillograph is a very costly and elaborate piece of apparatus. What is badly wanted is a portable instrument to give the wave-form at a glance. The question of standards has not received enough attention, especially for alternating-current work, standards for which, I think, are in a very unsatisfactory condition at the present time. Of course some test-rooms can spend very large amounts on test-room equipment. We do not object to spend £100 if we can get something reliable. There is the alternating-current potentiometer which has recently been put on the market. I do not know whether Mr

* *Journal of the Institution of Electrical Engineers*, vol. 44, p. 222, 1910.

Fawssett has any results of that instrument. With regard to phase shifters, I had one sent to me, but unfortunately it was one of the very first 3-phase ones made a few years ago, and I found that this had several drawbacks, one being that the voltages of the three phases were not equal, and the phase relationship was not exactly corrected. At the present day the designs are much improved, and it is now a very satisfactory instrument. For standards we want something we can check on alternating current and direct current, and I would like to know if any one has any information on Gossen's thermal millivolt-ammeter, which Messrs. Isenthal introduced eighteen months ago. I have looked into the question several times, but I have not obtained any reliable information on the subject, and am not able to experiment with it. Mr. Longman.

Mr. F. WALKER: The first supply company I was connected with had no testing department at all. Many people altogether neglect their meters, and that is the reason why I am glad to see that Mr. Fawssett has brought this matter forward. With regard to the testing of polyphase meters on single-phase circuits, I do not propose to say very much, but I think it is the better method. When, however, it is not convenient, the meters may be tested on a polyphase circuit. Under the latter condition there is, of course, some interaction between the elements, but this can easily be compensated for when testing on one phase only. Mr. Walker.

Mr. J. SCHUIL: With regard to lead on current transformers, I would like to ask whether Mr. Fawssett has found that the leading power factor becomes smaller as the load increases. In potential transformers there is supposed to be a small leading angle: is this the same at all loads? Is the accuracy of ratio much affected by putting a few lamps on the potential transformer? In reference to testing 3-phase meters for various power factors by reversing the leads as shown in the table, has this been confirmed by tests made on actual inductive loads of the same power factor? Is the reading obtained with the altered leads correct? Regarding the question of testing wattmeters with their current transformers, when testing for high-tension circuits it would become impossible to test wattmeters with current and potential transformers owing to the large power wanted, and, moreover, it is more accurate to test the meter with a pair of 5-ampere wattmeters than to read the larger currents for, say, 2,000 amperes or more; and in the case of such large meters I have found a current transformer far more accurate than a meter, or even a Kelvin balance. With the current transformer one can get twenty readings in succession with, say, 0·1 per cent. difference, which with meters for such large currents it is very difficult to get within a ½ per cent. for all alternating-current measurements. I find a current transformer with a 5-ampere dynamometer the most accurate method. Mr. Schuil.

Mr. C. TURNBULL: On a 500-volt meter there is at least 10,000 ohms in series with the commutator, so that any variation of contact resist- Mr. Turnbull.

Mr. Turnbull. ance can have no appreciable effect. The whole difficulty must come from the increased friction of the brushes, and yet this is difficult to understand seeing how light the brush pressure is. Meters have been made with gold commutators, and this would appear to be an advantage, especially with large meters. The question of testing meters in position has been raised, and in many cases this is desirable. Stray fields have a great effect on meters when placed on switchboards, and these can only be taken into account when the testing is done in position. Some makers state that their meters should be run round at full load before testing. This, however, is a very undesirable procedure. Meters have been known which gave good results if run at full load before testing, but which gave a bad curve if started at low loads and run at gradually increasing loads. In actual practice meters do not get a full load run at the beginning of the evening load, and unless they are correct when started at low loads the meters are of no use.

Mr. Bland. Mr. A. V. BLAND: It seems to me that the matter of chief interest is with regard to testing meters *in situ*. The reason that manufacturers are so anxious that supply companies and corporations should make rigorous tests on all meters, is that if they are found to be accurate in the test-room it shows that they have stood the journey, and there would then be no question of damage in transit.

Mr. Carter. Mr. THOS. CARTER: I prefer switches to plugs for such purposes as ammeter calibration, since switches are convenient for rapid adjustments; but plugs are perhaps better for machine testing-boards, where a given combination may last for a day or two. Plugs are also cheaper to repair in cases of a short circuit occurring. I am interested to hear of the alternator with the rocking field, as we have recently installed a similar piece of apparatus in our calibrating-room for getting phase differences in calibrating alternating-current instruments. The set is actually made up of two rotaries with a speed range of 600 to 2,400, for the purpose of getting varying periodicities. With regard to the question of filing particulars of windings and tests of machines, my own system is to put all the particulars of each machine into an envelope and file the envelopes in a drawer. This vertical filing system has been evolved through various stages from an original system of having all particulars entered into large record books, on which a great deal of time had to be spent; the latest system saves practically all this time and is equally convenient, as all details of a machine are collected together once for all, and can be referred to in full at a moment's notice. In the works with which I am connected, about one-third of the test assistants are drawn from the shops, and remain in the test-room for eighteen months, afterwards going back to the shop from which they were drawn. It is found that such a youth, who has served some time in testing as well as in the shops, is really useful on outside work in cases of emergency, as he is much more independent than if he has had only one part of this training. We have difficulty in getting our men to realise the great care which should

be taken in using instruments when testing machines, probably because they are more familiar with the details of machine construction than with the mechanism of instruments. We often get very extraordinary results, especially from wattmeter readings. Unless these are very carefully read, and (what is much more important) very frequently checked over, it is quite easy to get readings, in testing induction motors, say, which give values of the power factor greater than unity. Mr. Carter.

Mr. J. HIKELEY: With regard to testing meters on consumers' premises, I have had over twenty years' experience, and I find it a much easier matter to convince a consumer that his meter is correct or otherwise if it is tested on his own premises than if we removed it to our test-room to be tested. Ten years ago the practice was to remove all meters under dispute to our test-room to be tested, but we found this most unsatisfactory. We have some 9,000 meters in commission, and these are all changed periodically with the exception of the large manufacturers' meters, which are all tested in position, and I do not think that when a large meter is due for testing we could very well go to some of our consumers and tell them that we intended to remove the meter for testing purposes. They invariably insist upon all tests being carried out *in situ*, and where there are very large consumers one is practically bound to test in position, otherwise one will never be able to satisfy them as to the accuracy of the meter; and I think they have a perfect right to witness the test under working conditions. Mr. Turnbull has dealt with this matter, and is of the same opinion. Now we come to the question of records of all meters. We adopted the card system, and have no books. Each meter has a separate card, showing the date received, tests, and any other information, which gives the full particulars of the meter. When the system was handed over to me over twenty years ago by Mr. H. Faraday Proctor, the consumers' and meter information was recorded on a sheet of paper. We discarded this and adopted books in the form of a Consumers' Register, which we used up to ten years ago, when the card system was adopted for all information in connection with both meters and consumers, and we have found this extremely satisfactory. Mr. Hikeley.

Mr. F. O. HUNT: I would like to ask a question respecting one slide which does not appear to have caught other people's attention very much. This was a photograph showing an instrument for comparing alternating current direct with continuous current. I would like to know what degree of accuracy is attainable with that instrument. Some years ago Mr. Swinburne suggested an instrument for the same purpose but to be worked electrostatically. In comparing alternating-current and direct-current voltages I would like to ask if any special precaution has to be taken regarding the earth's field in using this instrument. I presume this paper is supposed to be confined to electrical testing instruments, but there are certain types of instruments quite as important to a power supply company as electrical instruments. I refer to the CO_2 and water recorders. In my opinion the CO_2 recorder is not fully appreciated. It is a common thing to Mr. Hunt.

Mr. Hunt. see engineers drawing up rigid specifications regarding dynamos, and striving after the last 1 per cent. in efficiency, while a much larger percentage of waste is being allowed to go up the chimney.

Mr. Fawssett. Mr. E. FAWSSETT (*in reply*): I am glad to have Messrs. Ratcliffe and Moore's remarks, and will deal with them together. Some of the points raised are due to only a short abstract being available before the meeting. As to examination of meters on circuit, our experience is the direct opposite; meters, and especially direct-current types, which are affected by stray fields, ought most certainly to be tested under the conditions which they experience at the consumer's, and this can only be properly done on site. I could mention several cases where the meters would have been seriously wrong if not so tested, and Mr. Ratcliffe's own experience of switchboard fields ought to convince him. In the case of alternating-current meters it is not so essential, but is so simple and accurate, and the meter stock is thereby so reduced, that it is much the most satisfactory course. As to plug and bar switchboards, this type is admittedly the best for laboratory work, and as the cost of equipping certain testing circuits specially is greater than making them conform to the rest of the board and thereby gaining in universality, it seems the most natural thing to do this latter. The board easily deals with currents up to 500 amperes, is handled daily by practically all the staff, and in seven years there has been no accident, so it cannot be difficult to understand. As to book-keeping, ordinary meter work needs nothing beyond the card system—the original rough test sheets (on specially printed forms) being filed as a record of work done—instruments, etc., periodically calibrated, also have a card record. But, as stated in the paper, "Stores" in this connection simply means the fixing department (which is separate), and special tests are all made out as reports as part of the general filing system. A potentiometer is, when suitably adapted for it, very convenient indeed for direct-current power measurements on site when the load is at all reasonably steady, and snap readings against indicating instruments on the alternating-current side of converting plant will agree with one another very closely. A single-pivot galvanometer replaces the usual spot of light indication for this work.

I will try and reply to the various criticisms made on the question of testing polyphase meters. Suppose we have a large capacity meter requiring current and pressure transformers for a supply of, say, 2,000 amperes capacity. The meter has to be tested for the following characteristics, and as each reacts on the others several cycles of tests are usually necessary before the meter can be passed as correct: (*a*) balance between torque of elements, (*b*) power-factor adjustment of each element, (*c*) registration at full load and unity power factor, and (*d*) "curve" for loads thence to zero. Consider the power used for such a set of tests even on two circuit testing, and the heavy connections involved for 3-phase connection (I do not admit, as the paper shows, the correctness of single-phase tests) whereas the current trans-

Mr. Fawssett.

formers may be tested in a few minutes at unity and zero power factor (using some external source of voltage) and so their characteristics determined. The meter tested separately can be run through a whole set of tests on a 10-ampere 3-phase lamp-board, having each phase stepped, so that the load is practically balanced, and the wave-form never distorted.

Mr. Maccall's remarks, very true in themselves, do not affect the case when both system and small machine waves closely approximate to a true sine. (The wave-form of the power supply on the North-East Coast is within 1 per cent. of a true sine.) The lampboards forming nearly all the impedance of the circuit, the small reactance of the meter coils does not affect the wave. The series coil of an ironless wattmeter has no effect on the characteristics of a current transformer, and may be left out of the calculation, but the iron-core coil of an induction wattmeter has more effect, and this is why I stated it should be included when testing for ratio. As to the "approximate" power factors obtainable by the cross-connected lampboard method this does not matter in the least. The most useful power factor tests are 0·5 lag and 0·5 lead, and as a wattmeter is in circuit with each phase, any slight positive reading can be noted, and a negative one also by using reversing switches provided for this purpose. For quadrature tests it is only necessary to switch on a small additional load on the phase not passing through the meter to get the exact result. I do not see how the interaction difficulty can be got over except by the method indicated, viz., testing the meter with the elements connected to the phases as it is to be used. This necessitates a proper system of colouring in the sub-stations, etc., but any well-designed system would have that. It is not possible to test it single-phase and put it up indiscriminately on any polyphase connection, and I do not see that interaction can possibly be correctly allowed for on a single-phase test.

Mr. Holden is right in saying that the Engineering Standards Committee Specification is becoming out of date, as we test regularly all types down to 2½ per cent. of full load, and ampere-hour meters to 1 per cent. of full load, this last being one of the most useful tests on the meter when kept on for some days. Shunted meters have been adopted for direct-current watt-hour work in this district for the very reasons Mr. Holden states, as well as the additional advantage that they are readily tested in position. Some of Mr. Longman's valued criticism I have already answered. As to interaction between elements being altered when the phases are not strictly 120° apart, this must be negligible as the total effect of reversing the flux is—as shown in Table II.—small, and therefore a small change in the angular relationship cannot have a measurable effect. As to standards, I think there are several weak points in the alternating-current potentiometer as at present manufactured, especially the milliammeter with its small scale and fiducial mark, to read on alternating current or direct current, and prefer reference to good, honest direct-current volts and amperes, taking reversed readings, and making quite sure that results are not

Mr. Fawssett.

vitiated by inductive or capacity effects. As a further link between alternating current and direct current a double dynamometer, with no control save that due to the main coils, may be used, one element carrying direct current which is checked on a potentiometer, the other the alternating-current to be measured. This latter part of the instrument must contain no unnecessary metal.

With regard to Mr. Schuil's query about lead on current transformers, the angle does usually tend to become somewhat smaller with increasing load. The accuracy of ratio of a potential transformer depends on its characteristics. Some such have a fairly high resistance primary winding (thousands of ohms) and then the ratio cannot be maintained with increased load on account of copper drop. I have made careful tests on such transformers, and the resulting change in ratio is nearly all traceable purely to copper drop on the primary. A 60 : 1 6,000-volt 200-watt pressure transformer may show as much as 2 per cent. change in ratio from no load to full load.

I am glad to have Mr. Hikeley's confirmation of my insistence on testing large meters on site and to note his remarks about the consumer's favourable attitude towards this practice, which agrees with my own experience.

In answer to Mr. Hunt, the alternating-current-direct-current balance has more than one range on the alternating-current side, so that it can always be worked at a high torque, and being dependent on a square law the control so obtained is very powerful and the accuracy high—of course reversed readings must always be taken in such a place as a test-room to eliminate stray fields.

THE MAGNETIC PROPERTIES OF SOME MANGANESE STEELS OF DEFINITE COMPOSITION.

By EZER GRIFFITHS, B.Sc.

(*Paper first received June* 26, 1911, *and received in final form August* 14, 1911.)

The influence of the manganese on the magnetic properties of manganese steels has been the subject of many investigations.

Barrett, Brown, and Hadfield * found for annealed alloys containing increasing quantities of manganese a considerable drop of permeability when the manganese rose from 2½ to 4½ per cent. They also found that carbon in the presence of manganese had a considerable effect. Unfortunately the percentage of carbon in their manganese alloys is not constant: varying from 0·24 in the 1½ per cent. manganese alloy, to 0·41 in the 2·25 per cent. manganese alloy, and to 0·08 in the 3·5 per cent. manganese alloy.

Burgess and Aston,† working with nearly pure iron manganese alloys, found that the permeability of the alloy containing 0·5 per cent. manganese was only slightly less than that of standard electrolytic iron. With 1 per cent. manganese the permeability was appreciably less, and with a further increase to 2 per cent. the alloy becomes of comparatively low grade.

Hadfield and Hopkinson ‡ were unable to discover any simple relation between the percentage of manganese and the reduction in permeability.

They suggest that, besides carbon, other variables—such as the temperature to which the alloys happen to have been subjected in rolling or forging, and the precise mechanical character of that process—have considerable influence on the magnetic properties of manganese alloys.

The steels whose magnetic properties are recorded in the present paper have had their chemical structure and microstructure carefully studied by Professors Arnold and Read in their work on "The Chemical and Mechanical Relations of Iron, Manganese, and Carbon." §

The specimens obtained from Professor Read were in the form of

* *Journal of the Institution of Electrical Engineers*, vol. 31, p. 674, 1902.
† *Metallurgical and Chemical Engineering*, vol. 8, p. 79, 1910.
‡ *Journal of the Institution of Electrical Engineers*, vol. 46, p. 235, 1911.
§ *Journal of the Iron and Steel Institute*, vol. 81, p. 169, 1910.

short cylinders 7·4 cms. long by about 1 cm. diameter. It was particularly requested that they should not be subjected to any mechanical or heat treatment. The extreme shortness of the specimens rendered the task a difficult one, although the chief object was accurate comparative results.

Preliminary experiments were made, using a magnetometer method, but owing to the high demagnetising effects of the ends the curves showing the relation between the magnetic force produced by the solenoid around the specimen and the intensity of magnetisation bore no resemblance to the usual form, being practically straight lines closely bunched together. However, the falling off in magnetic properties due to the presence of manganese was quite perceptible, particularly the rather considerable change between the 1 and 2 per cent. manganese specimens.

Efforts were then directed towards a suitable yoke method. The yokes first tried were rings of soft wrought iron, about 1½ in.

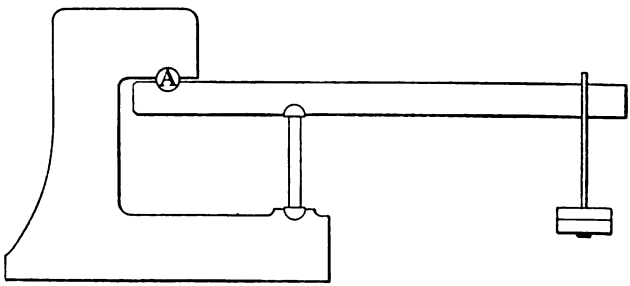


FIG. 1.

square section and 3 in. inside diameter. The specimen to be tested was fixed diametrically across the inside of the ring by two set pins screwed through the yoke, with their ends pressed against the end faces of the specimens. The magnetising coil, consisting of a secondary at the centre and a primary uniformly wound over, was slipped over the specimen before fixing in the yoke. The current through the magnetising coil was measured by an accurate millivoltmeter giving the potential difference at the ends of a low resistance through which the current passed. The changes of induction through the secondary coil were measured by the ballistic throws of a high-resistance D'Arsonval galvanometer. Although the type of yoke described above was discarded, yet the results obtained with it are of value, as they point out a precaution which must be taken in using yokes of such a type.

The results obtained for the manganese steels were very consistent, but similar experiments with a piece of mild steel of the same form as the specimens gave discordant results. At first it seemed that the

discrepancies were due to magnetic reluctance at the surfaces of contact between the specimen and set pins. An experiment on soft cast iron, suggested by Principal Griffiths, proved that the discrepancies were undoubtedly due to the effect of longitudinal pressure on the specimen, since an increase in the pressure produced by tightening down the set pins caused a decrease of as much as 15 per cent. in the induction corresponding to a given magnetic force.

Consequently it is inadvisable to use a type of yoke which sets a constraint on the specimen, as changes of temperature, which might be produced by the heat generated in the magnetising coil, can set up a considerable stress in the specimen.

The form of yoke adopted for the experiments of which the results are recorded in this paper is shown in Fig. 1. I am indebted to Mr. D. E. Thomas, M.A., B.Sc., for suggesting the lever arrangement, which permits the pressure on the specimen to be varied through a considerable range.

The novel feature of the apparatus, which overcomes some serious defects of the previous type of yoke, is the bearing arrangements suggested by Principal Griffiths.

It is essential that the connection between the various parts should be surfaces and not points or lines, as the magnetic circuit is closed through them. Here the plane ends of the specimen are in contact with the faces of two hemispheres of soft iron which fit accurately into corresponding hollows in the casting and lever. The hemispheres adjust themselves into contact with the end faces of the specimen, although these may not be exactly parallel. The joint at A is formed by a cylindrical roller of soft iron. The casting was of very soft grey iron, the lever and hemispheres of Lowmoor iron. Great care was taken to make the bearing surfaces fit accurately, and each part was ground into place. After several trials the following method was adopted for obtaining smooth plane ends to the specimens and hemispheres: The specimen to be faced was clamped in a special holder and worked into contact by a screw carriage with a rotating disc of copper whose surface was covered with very fine emery powder.

The surface produced was quite plane and smooth. A large number of experiments have been made with this apparatus, but in no case has the slightest discrepancy been detected which could be ascribed to variation in the contact reluctance. In these experiments no weight was added to the lever, so the stress amounted to 21 kilograms per square centimetre on the specimen. Hanging on weights and increasing the stress to 88 kilograms per square centimetre produced no effect which could be observed. Thus it appears that the variation of the magnetic properties of these hard steels with pressure is very slight, a fact which explains the agreement between the results of the various experiments with the round type of yoke used at first. Hysteresis curves were obtained by Evershed's method, starting from a maximum and reducing the magnetic force by continually increasing steps until it became

complete reversal. It was necessary to take into account the slight differences between the areas of cross-section of the specimens.

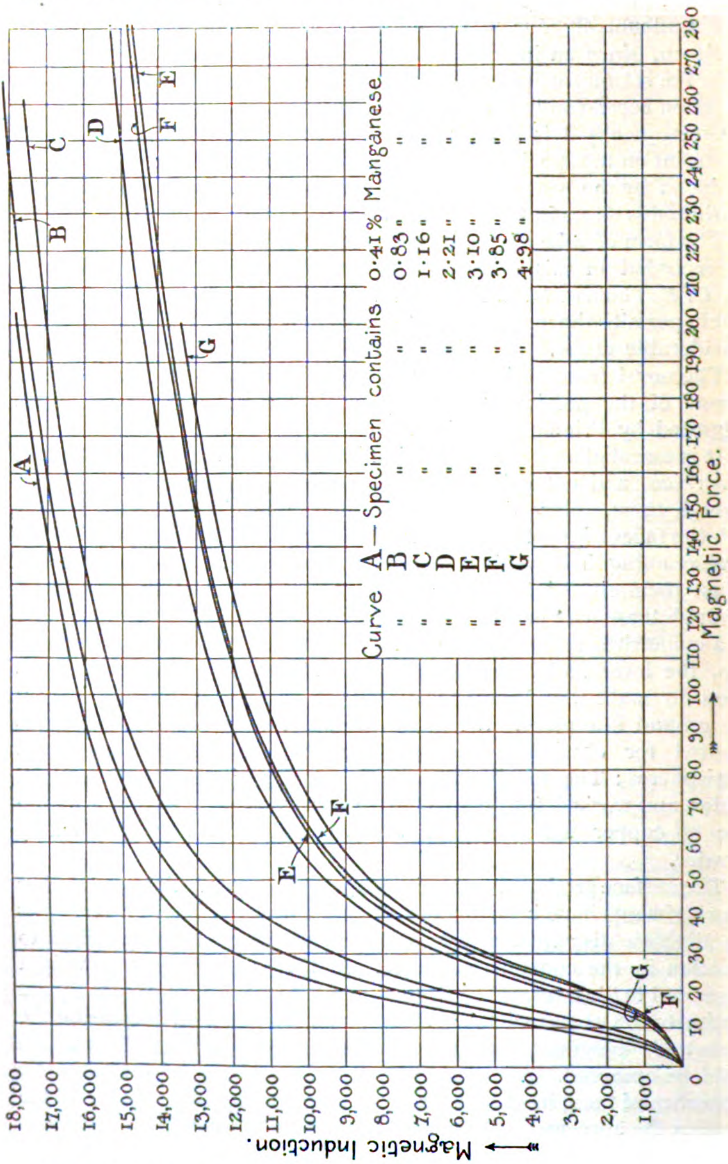


FIG. 2.

The absolute values given in the tables may be low on account of the resistance of the joints and yoke not being negligible. The comparative values, however, are accurate.

TABLE A (Fig. 2).

Relation between Magnetic Force and Magnetic Induction.

Magnetic Force.	Magnetic Induction in Specimens whose Percentage of Manganese is given at the Head of the Column.						
	0·41 per Cent. Mn.	0·83 per Cent. Mn.	1·16 per Cent. Mn.	2·21 per Cent. Mn.	3·10 per Cent. Mn.	3·85 per Cent. Mn.	4·98 per Cent. Mn.
10	3,550	2,500	1,800	700	630	570	600
20	9,000	7,550	6,300	3,500	2,980	2,450	2,400
40	13,430	12,410	11,170	8,250	7,700	7,460	7,050
60	14,870	14,220	13,300	10,400	9,800	9,690	9,200
80	15,620	15,180	14,420	11,600	10,990	10,900	10,410
100	16,200	15,800	15,130	12,390	11,750	11,700	11,230
120	16,600	16,280	15,650	12,970	12,310	12,380	11,850
140	16,960	16,690	16,100	13,450	12,780	12,850	12,330
160	17,270	17,010	16,490	13,840	13,140	13,200	12,700
180	17,560	17,300	16,770	14,150	13,450	13,530	13,060
200	17,800	17,580	17,000	14,430	13,750	13,880	13,440
220	—	17,780	17,200	14,700	14,020	14,190	—
240	—	17,970	17,410	14,900	14,270	14,400	—
260	—	18,110	17,600	15,120	14,500	14,610	—

RESULTS.

The following data and analyses concerning these particular specimens are given by Professors Arnold and Read in their paper already

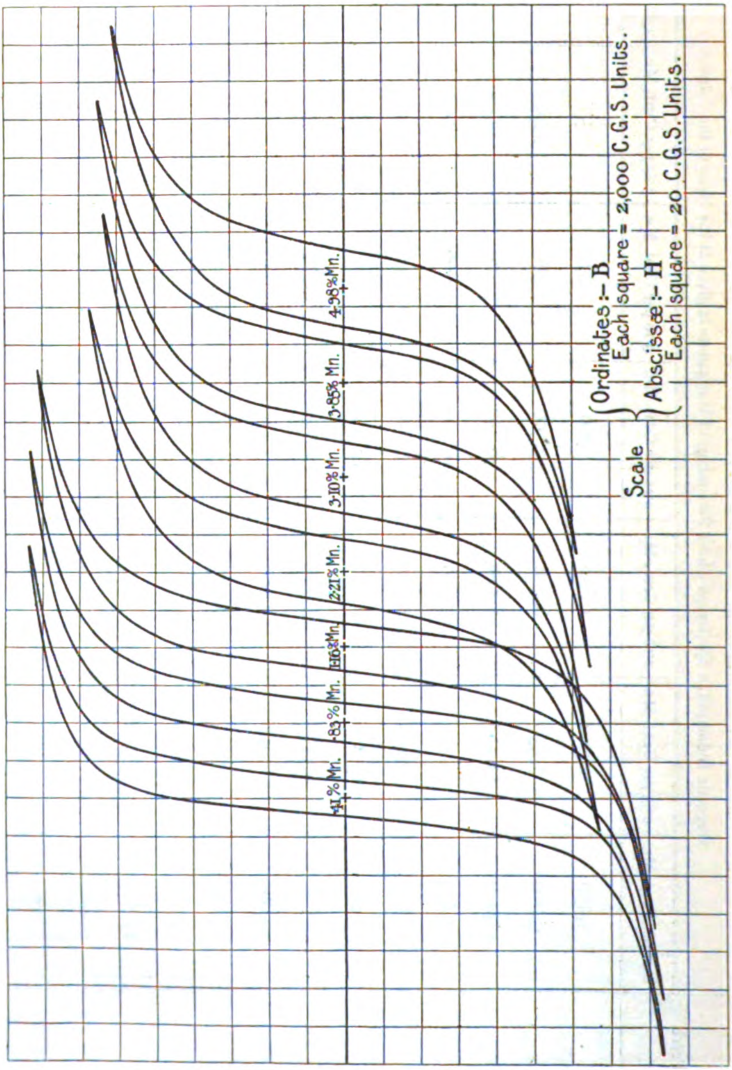


FIG. 3.

referred to, and are of interest in connection with this paper: "The alloys were made as nearly as possible to contain 0·9 per cent. of carbon with ascending manganese. The bars obtained after casting and

rolling were annealed by being heated to bright red heat for about 36 hours, and allowed to cool slowly during about 3 days. This drastic annealing gave the alloys an ample opportunity to crystallise out fully or segregate into their carbides."

ANALYSIS OF THE SPECIMENS OF STEEL.

Carbon, per Cent.	Manganese.	Silicon.	Sulphur.	Phosphorus
0·78	0·41	0·06	0·03	0·02
0·78	0·83	0·08	0·04	0·02
0·85	1·16	0·09	0·04	0·02
0·86	2·21	0·11	0·03	0·02
0·88	3·10	0·13	0·02	0·02
0·81	3·85	0·09	0·02	0·02
0·87	4·98	0·18	0·02	0·02

TABLE B (Fig. 3).

Percentage of Manganese.	Energy Dissipated in a Complete Cycle.	Retentivity.	Coercive Force.
0·41	50,720	9,000	9·42
0·83	57,400	8,500	10·62
1·16	61,800	8,480	12·50
2·21	64,600	7,000	16·90
3·10	66,100	6,800	18·85
3·85	74,860	7,240	20·44
4·98	67,500	6,680	20·44

Examination of the above tables and curves shows :—

1. That the addition of manganese causes a falling off in the magnetic properties, there being a considerable difference between the 1 and 2 per cent. manganese alloy.

2. The specimen containing 3·85 per cent. is noteworthy. For low magnetising forces its permeability is less than that of the specimen containing 4·98 per cent. manganese, while at a force of about

100 C.G.S. units its permeability is equal to that of the 3·1 per cent. alloy; for higher forces its permeability is greater than that of the 3·1 per cent. alloy.

Fig. 4 shows that the area of its hysteresis loop is greater than that of any of the others in the series. This was considered to be so strange that the entire series of observations were repeated some months later with the conditions somewhat changed. Several pieces of the apparatus were altered; for instance, the high-resistance galvanometer was replaced by a dead beat one. The results of this new series fully confirmed the previous results.

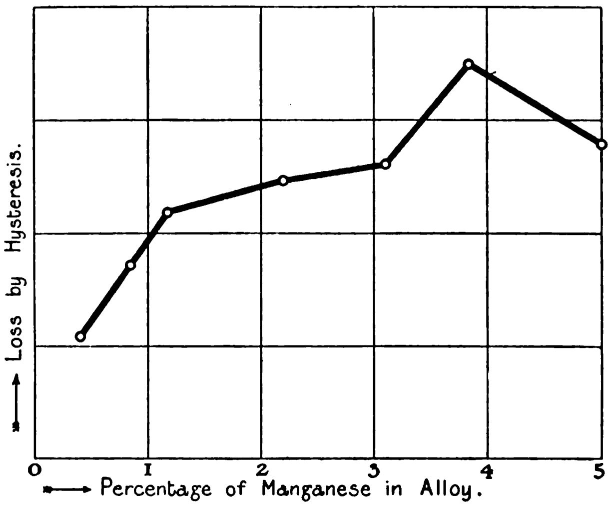


FIG. 4.

Professors Arnold and Read found that the micrograph of this specimen reveals a structure of coarse and flaring crystallisation, different from the others, which are of a fairly even texture. Chemically it was found to be quite normal. In tensile strength tests it broke down under a smaller load than either the one above or the one below it in the series. This seems to indicate that crystalline structure has a close connection with the energy dissipated by hysteresis.

My thanks are due to Professors Arnold and Read for the loan of the specimens; to the Education Committee of the Glamorgan County Council for contributing towards the expenses of the inquiry; and to Professor Selby for proposing this research, and for many valuable suggestions during the early part of the work.

SINGLE-PHASE COMMUTATOR MOTORS, ESPECIALLY THE LATOUR-WINTER-EICHBERG TYPE.

By G. W. P. PAGE and G. J. SCOTT, Students.

(*Abstract of paper read before the* STUDENTS' SECTION *on April* 26, 1911.)

The first part of the paper is devoted to a description of the simple alternating-current series motor, the reasons for its low efficiency, bad sparking, and low power factor, with the various attempts which have been made to overcome these defects, culminating in the Latour-Winter-Eichberg motor.

Fig. 1 shows the circuits of a repulsion motor of the Elihu Thomson type. By the simple expedient of transferring the winding W_1 to the rotor by adding a second pair of brushes C D, the Latour-Winter-Eichberg motor is evolved. The field flux N_1 is now produced by the

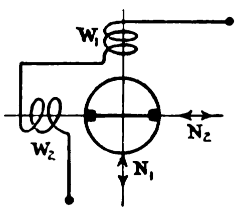


FIG. 1.—Thomson Repulsion Motor. W_1 and W_2 in Series. Armature Short-circuited.

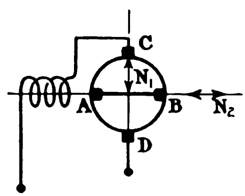


FIG. 2.—L.W.E. Repulsion Motor.

rotor, and the interaction of the current in the stator winding W_2 with this flux supplies the torque. The arrangement of the winding is shown in Fig. 2.

There are now two superposed currents in the armature: (1) the main current through the brushes C D, and (2) the current induced by the main current in W_2 flowing through the short-circuited brushes A B.

The main current flowing through the brushes CD produces a flux N_1. The stator conductors are lying at right angles to this flux, and carrying a current in phase with it, thus producing a torque between the stator and rotor.

Until the motor starts, practically the only flux in the axis of the short-circuited brushes A B is the flux due to the leakage between the stator winding and the rotor winding short-circuited by the brushes A B, forming a short-circuited secondary to the stator winding; and to the fact that the rotor has some resistance.

Directly the armature begins to rotate, its conductors will cut the flux N_1 (which always remains in the brush-axis C D) producing an E.M.F. in the armature sending a current between the short-circuited brushes A B. This E.M.F. is therefore used to drive this additional current through the rotor conductors, and is approximately 90° out of phase with the main current. These currents are best represented by means of a vector diagram (see Fig. 3). C_1 is the main current in the stator and the main axis of the rotor. N_1 is the flux produced by it, lagging a little by reason of hysteresis. C_T is the transformer current induced in the short-circuited axis, and is therefore approximately 180° out of phase with C_1. The E.M.F.

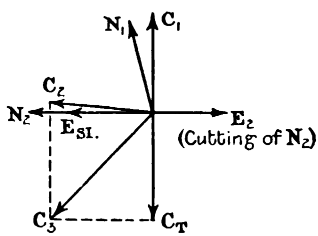


FIG. 3.—Vector Diagram for L.W.E. Motor.

induced at A B by the rotor conductors cutting the main flux N_1 produces in the short-circuited axis a current C_2, which, by reason of the self-induction of the rotor, lags nearly 90° behind the main current C_1. The resistance of the rotor tends to decrease this angle, whilst the phase displacement of N_1 behind C_1 tends to increase it. The transformer current being the resultant of C_1 and C_T is negligible.

The current, measured by an ammeter placed between the brushes A and B, will be C_3, the resultant of C_2 and C_T, but the flux N_2 in the short-circuited axis is chiefly due to C_2, for the currents C_1 and C_T almost neutralise one another. This current C_2 depends on the E.M.F. acting round the short-circuit path A B, *i.e.*, on the main current C_1 and the speed of the rotor; and, assuming the main current C_1 to be constant, C_2 will vary directly as the speed until at synchronous speed $C_2 = C_1$ (neglecting leakage). At the same time, of course, $N_2 = N_1$. Now the rotor conductors besides cutting the flux N_1 also cut N_2, and produce an E.M.F. at the main brushes C D in phase with N_2.

The E.M.F. of self-induction of the rotor, as we have seen, lags by 90° behind the main current C_1, therefore the E.M.F. E_2 will directly

oppose the E.M.F. of self-induction E_{SI}, and will gradually increase as the speed increases, until at synchronous speed the two E.M.F.'s are equal and the self-induction nil. The power factor of the machine will then be unity.

A number of experiments have been made by the authors to prove that this theory is correct.

1. The rotor of the machine was driven by an adjustable-speed direct-current motor, stator left unexcited and main current led into brushes C D, when it was confirmed that the voltage at brushes A B—left open-circuited—varied as the speed.

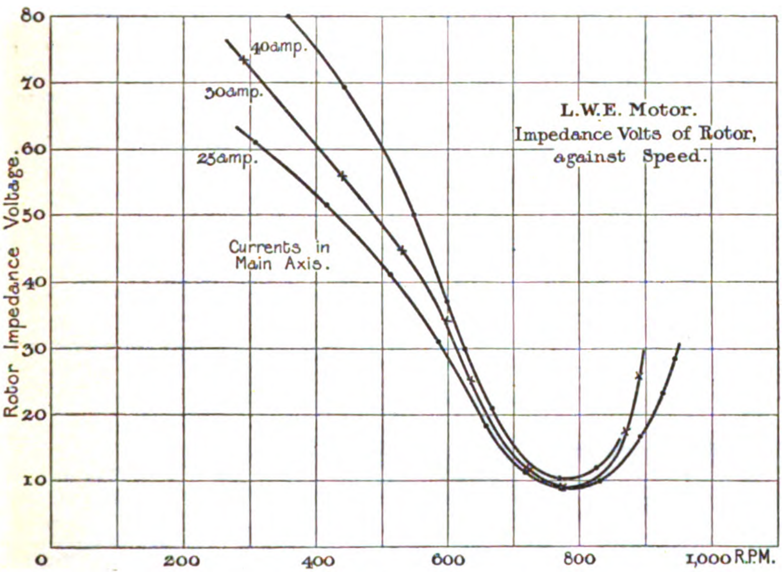


FIG. 4.

2. In this experiment the brushes A B were shorted and an ammeter measured the short-circuit current C_2 (Fig. 3) through the brushes A B. This was found to vary as the speed, and also the reading of a dynamometer, arranged with its fixed coil in one circuit and moving coil in the other circuit, was so near to zero as to be unreadable, thus showing that C_1 and C_2 are almost exactly 90° out of phase.

3. The motor was run as a short-circuited transformer, *i.e.*, current was led into the stator but not into the main brushes C D. A current was led through the stator, an ammeter, a non-inductive resistance, and the current coil of a wattmeter, the pressure coil of which was connected across the non-inductive resistance. The readings of the wattmeter proved that the currents C_1 and C_T (Fig. 3) are practically 180° out of phase.

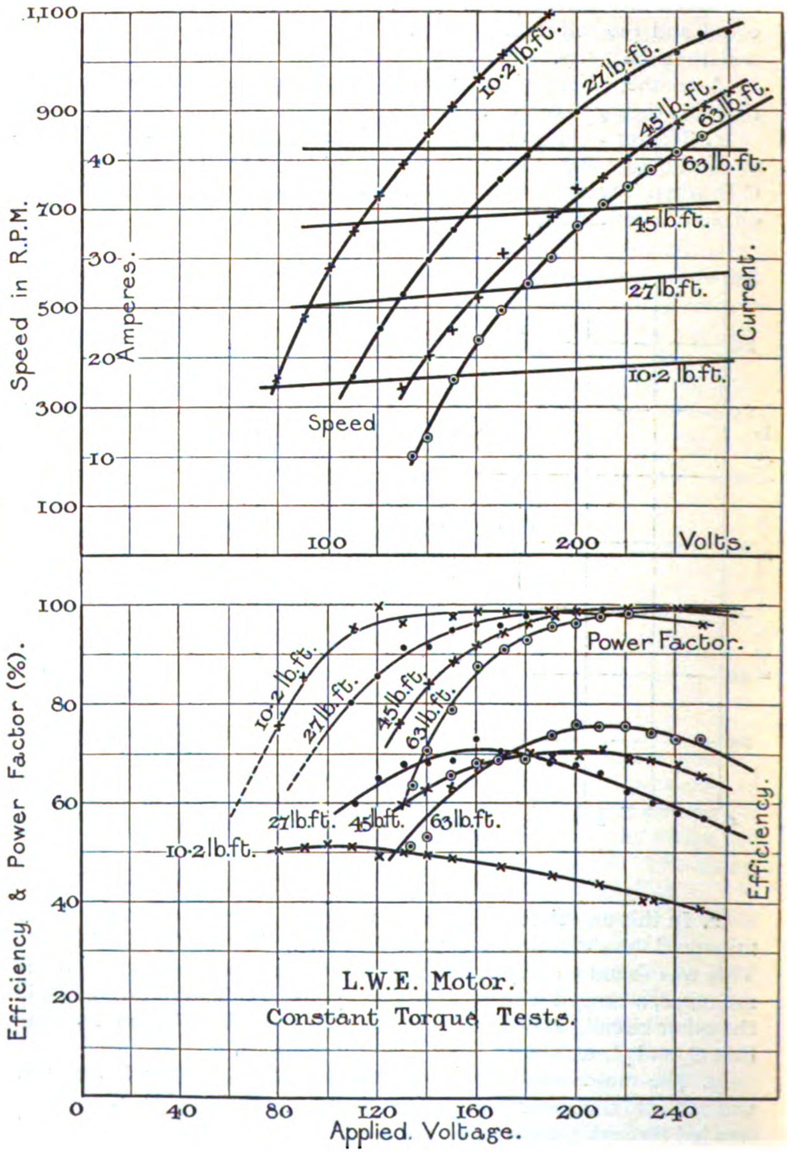

1,100
900
700
500
300
100
40
30
20
10
Speed in R.P.M.
Amperes.
10·2 lb.ft.
27 lb.ft.
45 lb.ft.
63 lb.ft.
63 lb.ft.
45 lb.ft.
27 lb.ft.
10·2 lb.ft.
Current.
Speed
100
200
Volts.
100
80
60
40
20
Efficiency & Power Factor (%).
Power Factor.
10·2 lb.ft.
27 lb.ft.
45 lb.ft.
63 lb.ft.
27 lb.ft.
45 lb.ft.
63 lb.ft.
10·2 lb.ft.
Efficiency.
L.W.E. Motor.
Constant Torque Tests.
0
40
80
120
160
200
240
Applied. Voltage.

FIG. 5.

4. The machine was run as a motor, *i.e.*, experiments 2 and 3 were combined, the current in the motor through the short-current brushes A B being now the resultant of C_2 and C_T (C_3 in Fig. 3). The readings of the wattmeter showed that C_1 and C_3 became more and more out of phase as the speed increased, because C_2 was increasing.

5. The machine was arranged as in experiment 2. As we have seen, the current C_2 in the short-circuit axis A B produces a flux N_2 in that axis which is cut by the conductors as the rotor moves.

This produces an E.M.F. E_2 at the main brushes A B directly opposed to the E.M.F. of self-induction of the rotor (Fig. 3).

It is evident that at synchronous speed E_{SI} and E_2 should be equal and opposite, and the impedance $= R$, where $R =$ the resistance of the rotor. They will, however, not be equal until a greater speed is reached because of the rotor leakage, the eddy current, and the rotor copper losses.

As N_2 is proportional to the speed and E_2 proportional to N_2 and the speed, then E_2 varies as the square of the speed.

Neglecting the resistance of the rotor, the impedance $= \frac{E_{SI} - E_2}{C}$; it will therefore fall rapidly as the speed increases up to synchronism and then rise again still more rapidly; we thus get the V-shaped curves shown in Fig. 4, where the minimum impedance occurs at 785 revs. per minute.

The performance of the machine under various conditions was also investigated. A Prony brake was fitted to produce a load and the machine connected to a 250-volt alternating-current supply through a variable resistance.

Tests were made with constant load, constant speed and constant voltage.

The results of the constant torque and constant voltage tests are shown in Figs. 5 and 6.

Below synchronous speed the speed will fall more rapidly than in a similar direct-current series motor, because in addition to the back E.M.F. being proportional to the current and speed, the impedance increases with a decrease in speed, but above synchronous speed, the compensating E.M.F. being large, the speed will increase less rapidly on account of the increase of the rotor impedance above synchronous speed.

The power factor does not change much at the higher voltages since for most loads the speed is at or above synchronism.

The various losses were investigated and the analysis of the iron losses is here given; the two fluxes N_1 and N_2 are not actually present, but are combined to form a resultant flux rotating uniformly at synchronous speed. As N_2 only becomes equal to N_1 at synchronous speed, the rotating field will only become uniform at that speed; at any other speed up to synchronous speed the curve traced out by the end of the flux vector will be an ellipse with its major axis on the main motor axis, and above synchronism with the major axis in the short-current axis.

As the resultant is always rotating at synchronous speed it is rotating faster than the rotor below synchronism, at the same speed at synchronism, and slower when above synchronism.

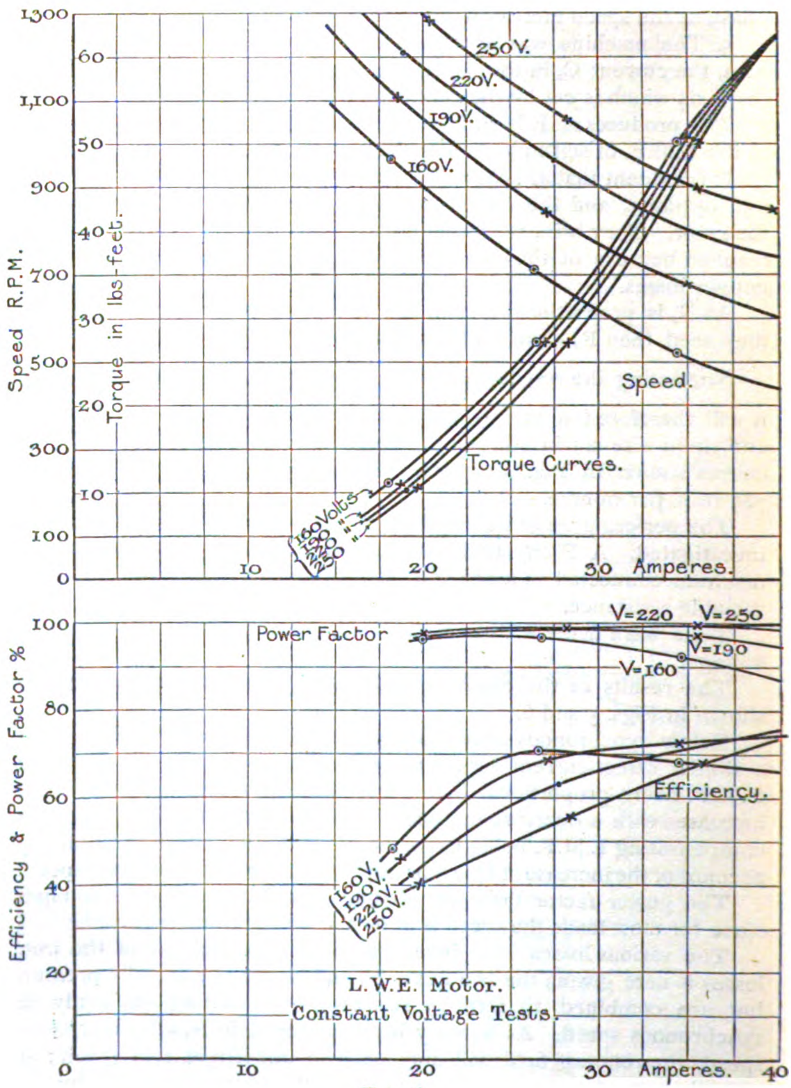


FIG. 6.

The various losses in the machine were found in the following way: The motor was driven at varying speeds by a continuous-current

machine through a belt. The stator being disconnected, a constant current was led into the main axis of the rotor only. A wattmeter was placed in this circuit with its pressure coil across the main motor terminals.

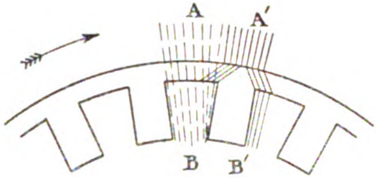


FIG. 7.—Diagram to show how Hysteretic Torque is produced.

The short-circuit brushes were short-circuited through the current coil of another wattmeter, the pressure coil being across the stator winding.

In this way the sum of the copper and iron losses was measured in

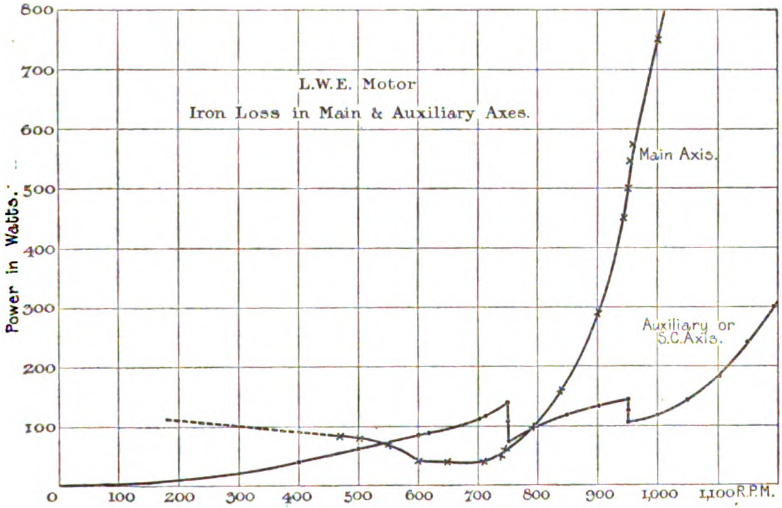


FIG. 8.

the main axis, but the copper loss being constant, the iron loss could easily be found.

In the short-circuit axis, however, only the iron loss is measured by the wattmeter.

The hysteresis loss in the rotor due to the rotating flux is equal to the product of a certain torque, which we will call the hysteresis torque, and the relative speed of the rotating flux and the rotor.

The diagram, Fig. 7, will make it clear how this torque is produced. Assume the rotor stationary; at some instant the position of the rotating flux is at A B. Immediately afterwards the flux in the stator will have moved round to A′ B′, but hysteresis causes some of the flux to remain in its original position, and, although there is a backward pull on the second tooth, yet the effect of hysteresis makes the forward pull on the first tooth greater, tending to turn the rotor in the same direc-

TABLE OF LOSSES AT FULL-LOAD TORQUE.

Stator current in each case, 41 amperes.
Rotor short-circuit current, 86 amperes.

Volts	160	200	240
Speed (revs. per minute)	435	660	815
Individual Losses as a Percentage of Total Loss.			
	Per Cent.	Per Cent.	Per Cent.
Stator—Copper loss	12·7	11·2	9·6
Iron loss	5·3	2·4	6·7
Main axis—Copper loss	14·4	11·6	9·6
Short-circuit axis—Iron loss	2·4	4·7	4·4
Copper loss	47·3	43·7	40·5
Brush loss	4·6	3·8	3·2
Frictional loss	13·3	22·6	26·2
Input in kilowatts	5·65	8·100	9·70
Losses in kilowatts	1·87	2·075	2·40
Efficiency, calculated (per cent.) ...	66·80	74·500	75·25
Efficiency on brake (per cent.) ...	66·00	75·000	74·00

tion as the rotating flux. This torque will remain until synchronous speed is reached, *i.e.*, until the speed of the rotor equals the speed of the rotating field, when it will suddenly disappear; but directly the speed of the rotor exceeds that of the flux an equal negative torque will appear, tending to retard the rotor. The result of this will be to give a sudden drop in the loss curves at synchronous speed. These curves are shown in Fig. 8. Besides the hysteretic loss, the total iron loss contains the following:—

1. Eddy current loss due to the rotating flux, in both axes. This is divided into loss in the stator and in the rotor.
2. Hysteresis and eddy current loss due to fluctuation of the flux in the teeth, as the teeth of the rotor and stator revolve past each other at a high speed. These are known as pulsation losses, and evidently depend on the speed of the rotor,

These oscillations cannot produce much variation in the main current, because of their very high frequency and small amplitude and the large inductance and resistance of the circuit. The power of the electric circuit will therefore supply very little of the power required to produce them, most of it being supplied directly by the driving motor.

Experiments were also made on variation of brush contact resistance and frictional and windage losses, so that the efficiency at various speeds could be predicted, and these agreed very well with those obtained on the brake, as shown in the preceding table, which also shows how large a proportion of the total loss is made up of the short-circuit copper losses. Means should therefore be found to increase the amount of copper on the rotor.

In conclusion, the authors would like to express their indebtedness to Professor T. Mather, of the City and Guilds (Engineering) College, for permission to carry out the above tests in the laboratories of the college.

NOTES ON THE DESIGN AND CONSTRUCTION OF DRY-CORE LEAD-COVERED TELEPHONE CABLES.

By H. C. MAY, Student.

(*Abstract of paper read before the* STUDENTS' SECTION *on February* 15, 1911.)

The following remarks are mainly devoted to some considerations of light-gauge cables used by the National Telephone Company for subscribers' lines.

Conductors.—Copper is at present exclusively used for the conductors, each of which consists of a solid cylindrical wire of pure annealed copper, smoothly drawn, and having a conductivity of 100 per cent., Matthiessen's standard. The sizes of the conductors are usually specified in terms of their weight in pounds per statute mile, and vary, in this country, between 6½ lbs. having a diameter of 0·02 in. and 200 lbs. of diameter 0·112 in.

Dielectric.—This consists of a mixture of air and paper. The paper is usually Manilla, specially manufactured for the purpose. High tensile strength is one of the most important properties. The specification requirement is a minimum tensile strength of 4,000 lbs. per square inch. Table I. shows results of some mechanical tests taken on samples of paper before being used in manufacture, and Table II. the results of tests on paper taken from cables supplied by three different cable manufacturers. The paper used for the 10-lb. conductors in Table I., and Sample C in Table II., are from the same manufacturer, and afford a good illustration of the reduction in tensile strength due to manufacturing processes. The paper varies in width from 250 to 500 mils, and in thickness from 2½ to 6 mils in cables containing conductors up to 40 lbs. per mile, though these dimensions may increase to 1¼ in. in width and 15 mils in thickness for 200-lb. conductors. There are two methods of applying the paper to the conductors. One consists in spirally lapping a paper ribbon round the conductors with an overlap, thus forming a closed paper helix. The paper is loosely applied so as to leave a certain amount of air-space between it and the conductor. The other method consists in covering the conductor with a longitudinal wrapping. The paper passes through a die by which it is formed into a tube loosely but completely enclosing the conductor. The paper is held in position by a whipping of cotton thread. The spiral method of insulating is considered to provide greater immunity from short circuits and contacts, there being less risk of the conductors becoming exposed when the cable is bent, and also to occupy a minimum amount of air-space in the core.

Table I.

Tensile Strength of Paper Insulation used for Telephone Cables.

Tests on Samples for 6½-Lb. Conductors. (Width, 0·25 in. Thickness, 0·0025 in.)				Test on Samples for 10-Lb. Conductors. (Width, 0·3125 in. Thickness, 0·0025 in.)			
Actual Breaking Load (Lbs.).		Breaking Load per Mil on Strip 1 in. Wide (Lbs.).		Actual Breaking Load (Lbs.)		Breaking Load per Mil on Strip 1 in. Wide (Lbs.).	
White Paper.	Red Paper.	White Paper.	Red Paper.	White Paper.	Red Paper.	White Paper.	Red Paper.
6·0	5·4	9·60	8·65	9·2	7·5	11·80	9·61
5·2	5·0	8·32	8·00	9·0	7·0	11·50	8·96
5·8	6·0	9·28	9·60	10·0	6·0	12·80	7·60
5·5	5·5	8·80	8·80	7·8	7·0	9·98	8·96
5·0	5·4	8·00	8·65	9·2	7·0	11·80	8·96
5·5	5·5	8·80	8·80	9·4	6·5	12·05	8·33
5·2	5·6	8·32	8·95	9·0	6·0	11·50	7·68
5·0	5·5	8·00	8·80	8·2	7·1	10·50	9·08
5·6	4·5	8·95	7·20	9·2	6·5	11·80	8·32
5·8	5·8	9·28	9·28	8·5	7·1	10·87	9·08
Mean 5·46	Mean 5·42	Mean 8·735	Mean 8·673	Mean 8·95	Mean 6·77	Mean 11·46	Mean 8·658

Table II.

Sample A. From 600-pair Cable (10-Lb. Conductors).				Sample B. From 400-pair Cable (10-Lb. Conductors).				Sample C. From 15-pair Cable (10-Lb. Conductors).			
Actual Breaking Load (Lbs.).		Breaking Load per Mil on Strip 1 in. Wide.		Actual Breaking Load (Lbs.).		Breaking Load per Mil on Strip 1 in. Wide.		Actual Breaking Load (Lbs.).		Breaking Load per Mil on Strip 1 in. Wide.	
White Paper.	Red Paper.	White Paper.	Red Paper.	White Paper.	Red Paper.	White Paper.	Red Paper.	White Paper.	Red Paper.	White Paper.	Red Paper.
4·0	1·5	5·80	2·175	5·0	4·0	6·66	5·33	4·0	3·8	5·34	5·65
4·3	3·5	6·25	5·080	5·0	2·8	6·66	4·40	3·0	3·3	4·00	4·40
3·3	2·0	4·79	2·900	2·8	4·0	3·74	4·00	5·3	3·0	7·60	4·00
Mean 3·9	Mean 2·33	Mean 5·61	Mean 2·33	Mean 4·27	Mean 3·60	Mean 5·68	Mean 4·68	Mean 4·1	Mean 3·4	Mean 5·647	Mean 4·68

Sheath.—The material for the sheaths of the National Telephone Company's cables is an alloy composed of 97 per cent. lead and 3 per cent. tin by weight. The thickness of this alloy sheath varies between 70 and 125 mils according to the size of the cable and weight of conductors.

Completed Cables.—There are at present three methods of cabling the wires together to form a cable, viz., ordinary twin, multiple twin, and quadruple pair. The cables to be described are of the ordinary twin type and are made up as follows: Two insulated conductors are twisted together to form a metallic circuit or pair. Each conductor of a pair is distinguished from the other by having differently coloured insulating papers, one being red and the other white or buff. The length of lay of the pairs is 4 or 6 in. according to the weight of the conductors and the number of pairs in the cable. The requisite number of pairs is then stranded together to form a symmetrical cable, the successive layers revolving round each other in reverse directions with a lay varying in length from 28 to 36 in. according to the size of the conductors. Two adjacent pairs in each layer are coloured blue and white and orange and white respectively. This enables, when necessary, the position of any individual pair, at any point where the core may be exposed, to be determined by counting in either direction from the marked pairs in the respective layers.

Over the centre and each successive layer a whipping of two or three cotton threads is spirally applied, enabling each layer to be easily recognised and facilitating the work of jointing. The core thus formed is served with two wrappings of paper not less than 4 mils in thickness, so laid on that all portions of the core are covered with at least two thicknesses of paper.

The completed core is then placed in a properly ventilated oven raised to a temperature of 225–230° F. in order to remove the moisture absorbed during the process of building up the core owing to the hygroscopic nature of the paper.

Immediately after leaving the drying chamber the core is sheathed with lead-tin alloy, which is applied under hydraulic pressure.

Fig. 1 shows a sectional view of a completed cable containing 800 pairs of 10-lb. conductors.

* *Multiple Twin Cables.*—The construction of this type of cable differs from that of the ordinary twin type inasmuch as the cabling consists of a series of twining operations. Two wires are twisted together to form a pair, two such pairs are twisted together to form a 4-wire core, and so on, until an 8- or 16-wire group be formed. The necessary number of groups are cabled together in the usual way. Where the requisite number of conductors is not exactly divisible by the number of wires forming a group, it is usual to utilise the interstices formed by stranding the larger groups together for the purpose of inserting additional single pairs or 4-wire groups, thus enabling any

* See "Design and Use of Telephone and Telegraph Cables," F. Tremain, *Journal of the Institution of Electrical Engineers*, Vol. 41, No. 192, 1908.

particular number of conductors to be embodied in the cable. An important point in constructing this type of cable is to vary the length of lay.

* *Quadruple Pair Cables.*—Four pairs of wires are twisted together to form a core, the requisite number of such units being stranded together to form a cable (see Fig. 2).

Design.—For the efficient transmission of speech the product of resistance and electrostatic capacity must be reduced to the lowest value compatible with reasonable cost.

The three ways in which this can be accomplished are: (1) to increase the size of the conductors, (2) to place the conductors as far apart as possible, and (3) to use an insulating material of low specific inductive capacity. Considering the first point, any increase in the size of the conductors, while lowering the resistance, increases the electrostatic capacity and also the cost. Secondly, increasing the distance between the conductors increases the diameter and consequently the cost of the cable, and also reduces the capacity of the duct into which it is drawn. In regard to the dielectric, it is here that dry-core cable scores. The ideal dielectric is, of course, air, but it is necessary to have some continuous support to keep the conductors from coming into contact, and the Manilla paper previously described effects this object. The specific inductive capacity of the mixture of air and paper is 1·7 to 1·9.

In the matter of resistance and electrostatic capacity a compromise has to be made, and the following figures give the values now specified for cables of various sized conductors.

Weight of Conductor. (Lbs. per Mile.)	Mutual Capacity. (Microfarads per Mile.)	
	Max.	Mean.
6½	0·080	0·07
10	0·080	0·07
20	0·087	0·08

The effect of increase in temperature on the electrostatic capacity and insulation resistance is shown in Fig. 3, which gives the results of tests taken on a dry-core lead-covered cable with 10-lb. conductors.

For the construction of telephone cable it is necessary to know (1) the diameter of each conductor, (2) the number of pairs in the completed cable, (3) the wire-to-wire or mutual capacity of the conductors, (4) the thickness of the sheath, and (5) the external diameter of the cable.

* See "Design and Use of Telephone and Telegraph Cables," F. Tremain, *Journal of the Institution of Electrical Engineers*, Vol. 41, No. 192, 1908.

FIG. 1.—Telephone Cable.

800 pairs. 0·025 in. conductors (10 lbs. per mile).

External diameter	2·67 in.
Thickness of lead	0·125 in.
Approximate weight per mile ...	400 cwts.

FIG. 2.—Telephone and Telegraph Composite Cable.

2 conductors each 100 lbs. per mile (1 ordinary twin pair).
32 conductors each 100 lbs. per mile (4 sets of quadruple pair cores).
4 conductors each 200 lbs. per mile (screened telegraph worming cores).
29 conductors each 70 lbs. per mile (screened telegraph cores).

External diameter...	2·7 in.
Thickness of lead	0·160 in.
Approximate weight per mile	451 cwts.

In the case of ordinary twin cables, where all the conductors are of the same diameter, (1), (2), (3), and (4) are known, and the designer has only to determine the minimum external diameter. Generally speaking, in the case of composite cables the maximum number of pairs compatible with good speech transmission has to be determined, the diameter being limited according to the size of the duct into which it has to be drawn.

The diameter of the wire of an ordinary twin cable is equal to—

Diameter of central strand + 2 d (number of layers);

where—

d is the diameter of one pair of insulated conductors.

The number of pairs in the central strand varies in telephone cables from 1 to 5, and the number of layers from 1 to 15.

The diameter of the central strand can be calculated from geometrical considerations or by using the formula :—

$$\text{Diameter of central strand} = d\left(\operatorname{cosec} \frac{180^\circ}{\text{number of pairs}} + 1\right).$$

Thus if the number of pairs in the centre layer be 3, 4, or 5, the diameter will be equal to $2{\cdot}155\,d$, $2{\cdot}414\,d$, and $2{\cdot}7\,d$ respectively. Finally we have—

$$D = d\,(x + 2\,L)$$

where—

D is the diameter of the core.
d is the diameter of one pair of insulated conductors.
x is a coefficient depending upon the number of pairs in the central strand and has the values previously quoted.
L is the number of layers.

The diameter of a pair (d) depends upon the size of the conductor and the electrostatic capacity required. The following values of d will be found to agree with standard practice in the latter respect and are given for different weights of conductors :—

Weight of Conductor. (Lbs. per Mile.)	Diameter of Pair (d).
$6\frac{1}{2}$	0·075
10	0·078
20	0·121

The external diameter of the cable will be found, of course, by adding twice the thickness of the sheath to the value of D. The external diameter is, so far as the National Telephone Company is

concerned, practically left to the manufacturer, the only stipulation being that the external diameter of any cable must not exceed 2·625 in., this being the maximum size which it is advisable for general work to draw into a standard 3-in. duct. The suppliers are naturally anxious on the score of cost to enclose the cable in a sheath having as small a diameter as possible. On the other hand, the Company's interests, which are also in the direction of economy of space and cost, are safeguarded by the electrostatic capacity which is required. To obtain this the supplier has to avoid crushing the core, and this serves a useful purpose in assuring a free passage for dry air should the cable require pumping at any time. A further advantage is gained by this, as it

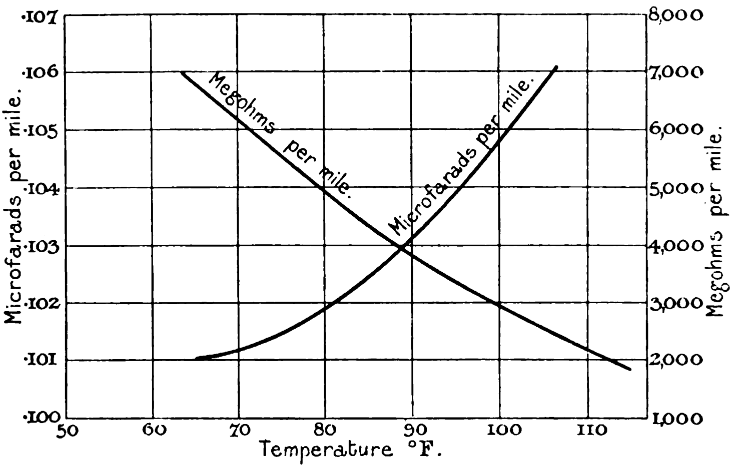


FIG. 3.—Variation in Insulation Resistance and Electrostatic Capacity of Dry-core Lead-covered Cable with 10-lb. Conductors due to Rise of Temperature.

provides a basis for stipulating a fixed diameter should one at any time be decided upon, and also secures comparative data as to the capabilities of the different suppliers in this respect.

The following design formulæ are empirical, being deduced from the results of past practice. Standard requirements as to the electrostatic capacity and insulation resistance have been assumed.

$$N = 4{\cdot}677 \times 10^5 \times d^{-2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

This formula gives the maximum number of pairs N of any diameter d (mils) which can be stranded into a sheath of internal diameter 2·375 in.

$$D \text{ (ins.)} = 0{\cdot}0855\, d \text{ (mils)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

From (2) the diameter of the core D of a 600-pair cable with any given diameter of conductor d can be calculated.

RECENT ELECTRIC LOCOMOTIVE PRACTICE AND THE HIGH-TENSION DIRECT-CURRENT RAILWAY SYSTEM.

By ALLAN MONKHOUSE, Student.

(*Abstract of paper read before the* MANCHESTER STUDENTS' SECTION *on November* 15, 1910.)

Electric locomotives may be divided into two distinct classes :—

1. Passenger locomotives for high speeds.
2. Freight locomotives for heavier service at lower speeds.

The requirements in design are in some respects different.

PASSENGER LOCOMOTIVES.

With express locomotives and speeds of 40 to 80 miles per hour, the blow delivered on the rail when the locomotive meets any transverse irregularity in the track is tremendous, and above 40 miles per hour increases out of all proportion to the speed. For this reason special precautions are necessary in high-speed locomotive design, and great attention must be paid in order that all parts possible may be spring-borne and the centre of gravity as high as possible above what is known as the centre of transverse restraint—that is, generally, about the axles. Should the centre of gravity be somewhere on the centre line of transverse restraint, then any track transverse irregularity will tend to turn the locomotive bodily in a horizontal plane about a vertical axis, and the whole of the force thus required to turn the locomotive is brought laterally upon the rail.

When the centre of gravity is high above the axles, any irregularity brings two rotations to bear on the locomotive ; one the same as already mentioned about a vertical axis, and the second a rotation about a longitudinal and horizontal axis passing through the centre of gravity. The riding springs deal with the forces due to this latter rotation and it becomes one acting vertically down on the rail face.

However, in this case it is obvious that should the great bulk of the locomotive weight be concentrated near the centre of length of the locomotive, the lateral blow exerted by the leading wheels on the rail is considerably lessened.

Further, considering the problem of horizontal rotation, we find that there is a certain zone that is neutral as regards transverse motion relatively to the track in passing an irregularity. Messrs. Storer and Eaton recently pointed out that if some form of gearless motor and other heavy parts were hung from this neutral part of the locomotive the rotation of the remaining spring-borne masses would be more easily accomplished. In such cases a sound flexible coupling is required between the motors and the axles. This is much the principle adopted in the New York, New Haven, and Hartford locomotives.

Considering these points, we have a choice of two types of machine for high-speed work:—

1. A machine with high centre of gravity.
2. A machine with its motors and as much as possible of its spring-borne parts suspended from the zone neutral to transverse movement of the locomotive.

A locomotive with high centre of gravity usually has its motors placed high in the locomotive cab or practically in the cab, allowing not only a high centre of gravity but easy inspection and freedom from dirt and damp under the locomotive. Such motors transmit to the axles in five ways, speaking generally :—

1. Through a yoke connecting the two motor crank pins to a pin in the centre driver.
2. Through a side frame closely resembling the above yoke, from which side rods run to the drivers.
3. Through inclined cranks on to a jack shaft, and thence through side rods to the drivers.
4. Through gears and jack shaft, and thence to the drivers through side rods.
5. Through flexible gears, that is, from motor pinion on to a spur-wheel, which is mounted on a quill surrounding the shaft and driving it, yet spring-supported from it in the manner of the N.Y., N.H., and H. loco motors.

Fig. 1 depicts these five constructions. Considering type (2) the N.Y., N.H., and H. locomotives adopt this construction, and hang the motors from a special framework. The armature is mounted on a hollow quill surrounding the axle. The end of the quill is provided with discs which drive the drivers through pins surrounded by springs. This allows a complete spring suspension for the motor. Recent practice has proved that for high speeds pony wheels and bogie trucks greatly improve riding qualities and assist in guiding. As much as one-third the total weight has been put on bogie trucks in the Pennsylvania locomotives. Modern electric locomotive wheel bases are reverting to the old wheel bases long the standard in high-speed steam locomotive work.

Slower Speed Passenger and Freight Locomotives.

These locomotives usually require a larger number of smaller drivers each separately driven, and the following two constructions are generally used :—

1. The ordinary geared motor per axle long used in tramway work.
2. Gearless concentric motors with the armatures rigid on the axles.

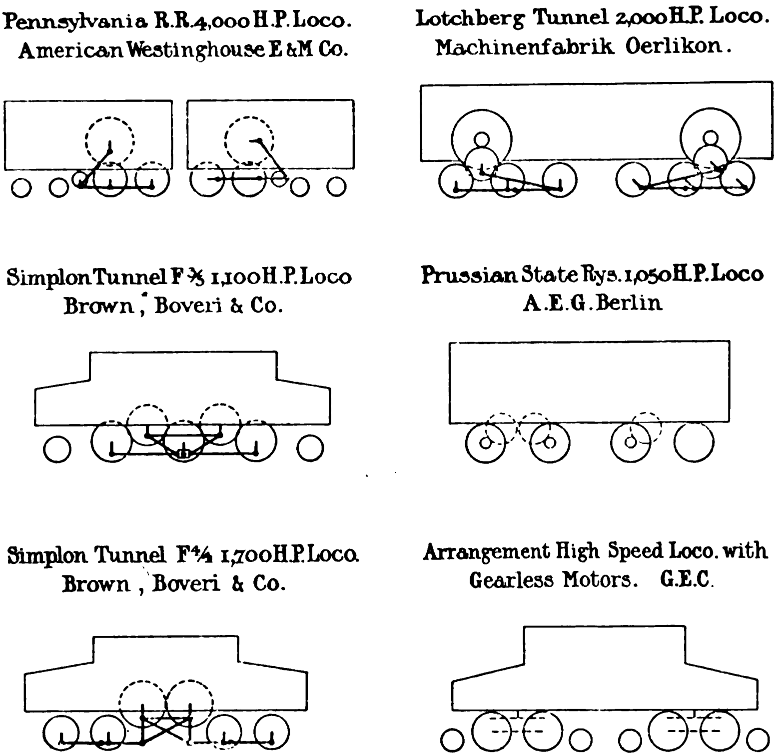


Fig. 1.

These constructions are simple, and afford a good slow-speed locomotive.

Coming to the second stage of the paper—the electrical equipment—it is the author's intention simply to deal with the high-tension direct-current locomotive.

The direct-current series motor is already well established in all

branches of electric traction, and is constructed up to 2,000 H.P. and 1,500 to 2,000 volts, and, further, it is true that the high-tension direct-current motor is as simple and satisfactory as its low-tension predecessor.

Not only does the high-tension motor share the advantages of the low-tension direct-current motor over its single-phase rival as regards (1) weight per horse-power, (2) weight of control equipment per horse-power, (3) increased air-gap allowing more bearing wear, (4) simplicity of control, (5) elimination of excessive sparking at starting due to heavy wattless currents found in alternating-current motors, but for a given size it is tremendously more powerful, as the narrow commutator required allows more active core-length.

The control equipment is most interesting, and in the Mosselhutte locomotives this appeared somewhat bulky; however, there is not the

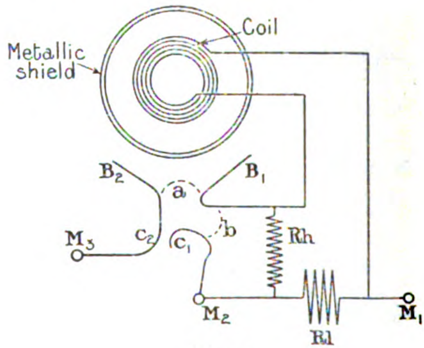


FIG. 2.

slightest reason why the contractor and blow-out apparatus for dealing with full-load currents at 3,000 and 4,000 volts should be more bulky than for 600 volts direct current. As the 600-volt direct-current equipment is shown in Table I. to be the lightest in comparison with any alternating-current system, we may therefore reasonably expect to find the high-tension direct-current equipment topping the list as regards lightness and simplicity.

The metallic shield blow-out employed by Messrs. Dick, Kerr & Co., due to Mr. T. von Zweigbergk, is extremely simple, and is shown in Fig. 2, from which it will be seen that its dimensions compare most favourably with those of any low-voltage blow-out. A brief description will be of interest. The main current is M_1, M_2, M_3, passing through very low resistance R L and contacts C_1 and C_2. In parallel with R L is a blow-out coil with a higher resistance R H in series with it, the value of which is about ten times that of R L. On breaking the contact C_1, C_2, the coil is sufficiently strong to pull the arc "*a*" up between the two jaws B_1 and B_2, and altogether to blow out the arc "*b*." Thus the arc "*a*" remains, and as "*b*" is ruptured the whole of the

TABLE I.

	Pennsylvania Railway.	Detroit River Tunnel.	Vancouver B.C.E.R.	Mosselhutte.	N.Y., N.H., and H. Gearless.	Valtillina.	Seebach, Wettingen.	Simplon Tunnel, F 3/5.	Lotchberg Tunnel.	Prussian State.	N.Y., N.H., and H. Goods.	Simplon Tunnel, F 4/4.
System	D.C.	D.C.	D.C.	H.T.D.C.	1-phase and D.C.	3-phase	1-phase	3-phase	1-phase	1-phase	1-phase	3-phase
Makers	Westinghouse	G.E.C.	Dick, Kerr & Co.	Siemens-Schuckert	Westinghouse	Ganz & Co.	Oerlikon	Brown-Boveri	Oerlikon	A.E.G.	Westinghouse	Brown-Boveri
Total weight (tons)	157	90	50	55	90	62	40	62	86	59·5	140	68
Adhesion weight (tons)	93	90	50	55	71·5	42	40	42	86	44·7	96	68
Mechanical weight (tons)... ...	100	65	34·5	—	41·5	30	23·5	34	44	—	82	33
Electrical weight (tons)	57	25	15·5	—	48·5	32	16·5	28	42	—	58	35
Total H.P.	4,000	1,200	640	640	1,000	1,500	400	900	2,000	1,050	1,400	1,700
Electrical weight per H.P. ...	0·0142	0·0208	0·0242	—	0·0485	0·0213	0·0413	0·0311	0·0210	—	0·0413	0·0206
Maximum speed, M.P.H.... ...	72	35	—	—	86	40	—	—	44	—	45	42
Normal speed of	60	12	15	—	60	40/26/15	—	42/21	26	19·5/17·5	35	42/31 26/15
With trailing load of	550	1,800	—	—	250	250	—	300/400	—	—	1,500/800	300/400
Maximum tractive effort	79,200	60,000	25,000	—	19,200	—	—	31,000	33,000	—	40,000	46,000
Normal ditto at rated speed ...	69,300	36,000	16,160	—	—	13,250	—	13,500	28,700	—	—	25,000
Wheelbase arranged	oo ⊖⊖ ⊖⊖ oo	⊖⊖ ⊖⊖	⊖⊖ ⊖⊖	⊖⊖ ⊖⊖	o ⊖⊖ ⊖⊖ o	o ⊖⊖⊖ o	⊖⊖ ⊖⊖	o ⊖⊖⊖ o	⊖⊖⊖ ⊖⊖⊖	⊖⊖⊖⊖	o ⊖⊖ ⊖⊖ o	⊖⊖ ⊖⊖
Transmission arrangement ...	Crank counter-shaft and rods	Geared each end of axle	Geared direct	Geared direct	Gearless concentric	Yoke and side rods	Gear and side rods	Yoke and side rods	Gears, crank, and rods	Geared direct	Flexible gearing	Frame and rods
Over-all length	70 ft.	—	35·5 ft.	34·2 ft.	36 ft. 4 in.	37 ft. 6 in.	30 ft. 9 in.	40 ft. 6 in.	—	—	48 ft.	37 ft. 6 in.
Rigid wheelbase length	7 ft. 2 in.	—	—	—	—	15 ft. 6 in.	—	16 ft.	—	—	7 ft.	15 ft.
Gear ratio	1 : 1	1 : 4·37	—	—	1 : 1	1 : 1	1 : 3·14	1 : 1	1 : 3·25	1 : 4·21	1 : 1	1 : 1
Number of motors...	2	4	4	4	4	1 and 1 auxiliary	2	2	2	3	4	2
Motor voltage and H.P.	600 V. 2,000 H.P.	600 V. 300 H.P.	600 V. 160 H.P.	1,000 V. 160 H.P.	250 H.P.	3,000 V. 1,500 H.P.	200 H.P.	3,000 V. 450 H.P.	1,000 H.P.	370 H.P.	350 H.P.	3,000/850
Weight of one motor (tons) ...	20	4·7	3·06	—	6·6	13·1	3·38	10·75	9·8	5·5	8·8	12·25
Ditto per H.P.	0·0100	0·0156	0·0191	—	0·0264	0·0087	0·0169	0·024	0·0098	0·0149	0·0251	0·0144
Weight of control apparatus ...	17	6·2	3·25	—	22·1	18·9	9·74	6·5	22·4	—	22·8	10·5
Ditto per H.P. of locomotive ...	0·0042	0·0052	0·0051	—	0·0221	0·0126	0·0243	0·0072	0·0112	—	0·0164	0·0062
Line voltage and frequency ...	600	600	600	2,000	11,000 A.C. 600 D.C.	3,000	15,000	2,700/3,300	15,000	6,600	11,000 A.C. 600 D.C.	2,700/3,300
Track supply	Third rail	Third rail	Overhead	Overhead	Third rail and overhead	Overhead and rail	Overhead	Overhead and rail	Overhead	Overhead	Overhead and third rail	Overhead and rail
Diameter of drivers	72 in.	48 in.	—	—	62 in.	59 in.	40 in.	64·5 in.	55 in.	55 in.	63 in.	63 in.
Type of motors	D.C. Ser.	D.C. Ser.	D.C. Ser.	H.T.D.C. Ser.	A.C.-D.C. Ser.	3-phase induction	1-phase comp. ser.	3-phase induction	1-phase comp. ser.	Comp. ser.	A.C.-D.C. ser.	3-phase induction
Type of controllers	Electro-pneumatic. Stunted field	Sprague M.U. contactors. Ser.-Par.	Zweigbergk M.U. contactors. Ser.-Par.	Hand operated. Ser. Par.	Electro-pneumatic A.C. and D.C.	Pneumatic water resistance in rotor C.C.	—	Pneumatic pole-changing and rheostats	Transformers (Auto)	Winter-Eichberg, with regulating transformer	Electro-pneumatic A.C.-D.C.	Pneumatic pole changing

current must pass round the blow-out coil, thus strengthening up the field so as to extend and completely rupture "*a*."

In breaking 400 k.w. at 4,000 volts the arc may be 8 or 9 ft. long, and a metallic shield to rupture this of the ordinary standard controller pattern would need to be 3 ft. in diameter. The actual dimensions of Messrs. Dick, Kerr & Co.'s shield is 6¼ in. This small size is secured by winding the blow-out coil with small gauge wire, since any heavy currents in the coil are only momentary, and thus an extremely high current density is allowable. Compactness is further obtained by directing the jaws B_1 and B_2 into two separate compartments, so that the arcs must make two complete convolutions before they re-unite.

The author believes the high-tension direct current will eventually be found the lightest, simplest, and most direct method of railway electrification.

With regard to track supply and return the high-tension direct current readily meets alternating-current systems, since there is no reason why 3,000, 4,000, and perhaps even 6,000 volts direct current should not be used without incurring risk or trouble. Considering the excessive rail return drop with alternating current systems, interference with telephones, and additional insulation for nominally the same voltage consequent upon the use of alternating current, it seems that the high-tension direct current has much in its favour. In comparison with 3-phase alternating current the high-tension direct current also meets this case in employing a 3-wire arrangement—either with a 3-wire locomotive and rail as middle wire, or with one outer over each track and rail as neutral as in the City and South London line. At stations such a system would be fed from one outer only.

The third rail is out of the question for supplying alternating current because of its high inductance, but there is everything in its favour for use with high-tension direct current. It is rigid, affords good contact surface, simple and cheap in maintenance and first cost.

Voltages of 1,200 and 1,500 volts are now successfully and satisfactorily employed on an inverted protected third rail 9 or 10 in. above the rail-level of the running rails, and there is no real reason why this should not be extended up to 3,000 volts.

EXHAUST STEAM TURBINES.

By R. C. PLOWMAN and E. F. HETHERINGTON, Students.

(*Abstract of paper read before the* STUDENTS' SECTION *on March* 15, 1911.)

The object of the exhaust steam turbine is to utilise to the fullest advantage the energy available in steam expanding below atmospheric pressure. Sometimes, as in the case of non-condensing engines, the energy in such low-pressure steam is entirely thrown away; in other cases, where condensing is resorted to, partial utilisation only is obtained. Fig. 1 shows the curve of adiabatic expansion of steam, the ordinates representing pressure and the abscissæ volume. The total area enclosed by the curve A B E F G represents therefore the theoretical amount of work done by a pound of steam in expanding between the pressures shown on the diagram—viz., 160 lbs. per square inch admission pressure and about 2 lbs. per square inch condenser pressure. It will be noted that each pound decrease in pressure below atmosphere corresponds to a very large increase in volume; for whereas the volume of a pound of steam only increases from 2·8 cub. ft. at 160 lbs. pressure to 25·8 cub. ft. at 15 lbs., it increases from 25·8 cub. ft. to about 260 cub. ft. at 1½ lbs. per square inch, or 28½ in. vacuum. On account of this rapid increase in volume it is found that an exhaust pressure of about 5 lbs., or a vacuum of 25 in., is the farthest degree to which it is feasible to carry the expansion of steam in a reciprocating engine; for below this pressure the enormous size of the cylinders required would quickly reach an impracticable limit. Moreover, steam expanding to such a degree acquires a very high molecular velocity, and its energy is only available in the kinetic form. To utilise kinetic energy, suitable impact surfaces for the moving molecules must be provided. The reciprocating engine does not give this condition, as its mechanism is designed entirely to utilise pressure. With the turbine the reverse is the case, the machine being designed to utilise energy due to velocity rather than to pressure.

It is therefore possible to utilise with the turbine the energy of the steam at pressures lower than can be done with the reciprocating engine. Taking the limit of expansion in the reciprocating engine as 4 lbs. per square inch absolute pressure, corresponding to the point D in Fig. 1, we see that the area H D E F G represents available energy which is not converted into useful work, being uselessly expended, chiefly in warming up the condenser water. This area, measured on

the diagram, is found be about 40 per cent. of the whole area A B E F G. The turbine reclaims almost the whole of this previously wasted percentage of the total amount of energy given out during the cycle, the ascertained efficiency compared with the theoretical duty of steam between these limits of pressure being found to be about 70 per cent. with a 27-in. vacuum.

It must be clearly understood that improvement in economy of operation can only be accomplished by an exhaust steam turbine when conditions require, or provide an opening for, more power than is being given out by plant already at work. But that such cases are of everyday occurrence may be seen from the following typical instances where the exhaust steam turbine has proved, or would prove, a paying investment :—

(*a*) An existing reciprocating engine running overloaded may have its load partly eased on to an exhaust steam turbine-driven dynamo.

(*b*) Where a works is being extended an exhaust steam turbine may provide sufficient power to drive the extensions.

(*c*) Many large works which are mainly steam-driven require a supply of electric current for subsidiary purposes, such as the driving of cranes, remote machines, and minor shops, lighting, etc., and in such cases the installation of an exhaust steam turbine coupled to the main engine or engines will save the expense of running independent live steam generating sets.

(*d*) In general, when any extensive conversion to electric drive of a large works takes place, there is frequently an opening for the exhaust steam turbine.

(*e*) Where an owner of exhaust steam would have no particular use for the power generated if he installed an exhaust steam turbine, it may be open to him to sell his steam to a syndicate or other body who will re-sell the power to those who do want it.

It is not necessary that the supply of steam from the primary engine should be continuous. Regenerative heat accumulators, of which the most extensively used is that designed by Professor Rateau,* have been put into successful use for the purpose of converting an intermittent steam supply into an even and continuous one. Such accumulators act in the manner of a "heat flywheel," absorbing heat during times of abundant exhaust and restoring it when the supply diminishes or fails. Such conditions occur in particular with rolling-mill and winding engines, which use enormous quantities of steam, but in a very irregular manner. For this reason such engines have always run non-condensing hitherto, and great amounts of energy in the form of exhaust steam have run to waste in the atmosphere. The exhaust

* C. S. Richards, *Journal of the Institution of Electrical Engineers*, vol. 43, p. 754, 1909.

steam turbine and heat accumulator provide a ready means of utilising such wasted energy. Thus, scattered steam engines become replaced by electric motors supplied by the turbine-driven generator, and most of the minor operations about the works or mine, together with the lighting, ventilation, and other requirements, are supplied by steam previously wasted.

Such an accumulator in reasonable sizes can cope with interruptions of supply of a few minutes' duration only, and it is nearly always necessary in cases where longer interruptions are to be accommodated

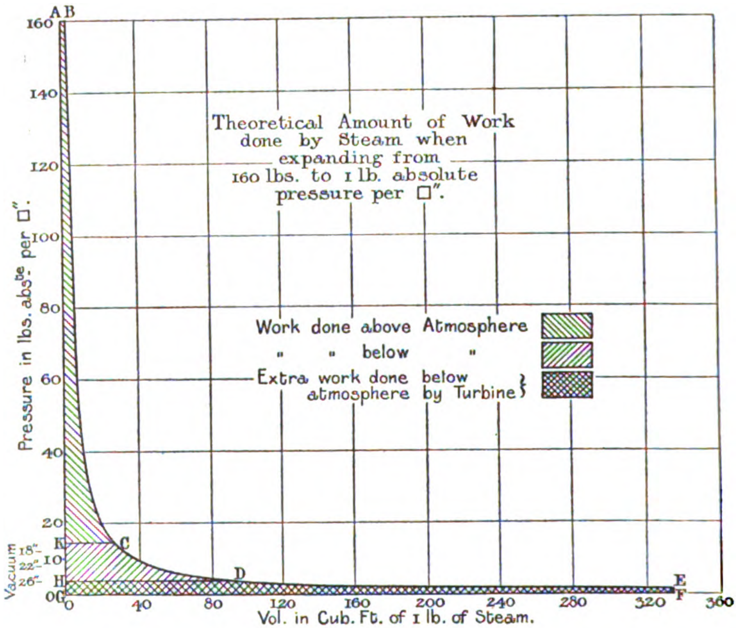


FIG. 1.

to install a mixed-pressure turbine, so that the turbine may be run on live high-pressure steam when the engines supplying the exhaust steam are not running. This turbine would have high-pressure and low-pressure stages with valves arranged so that should the low-pressure supply fail the high-pressure valve will open and the turbine continue in operation on live steam. The turbine may run on low-pressure steam only, high-pressure steam only, or a combination of the two, and any loss of energy due to passing the steam through a reducing valve is avoided.

A mixed-pressure turbine cannot take the place of a heat accumulator for rapid variations in pressure as, even though the high-pressure

valve would allow steam to pass as soon as the supply of exhaust steam failed, it would not be possible for these changes of admission to occur in time to prevent alterations in speed, and, moreover, the exhaust steam would come with such a rush that the turbine would not be able to accept it, and loss would occur through the relief valve.

Now as to the extra power, and consequent economy, which the exhaust steam turbine can provide in typical cases.

Non-condensing Engines.—Take, for example, a non-condensing engine of 1,000 I.H.P., using, say, 20 lbs. of steam per I.H.P.-hour. This would mean that 20,000 lbs. of exhaust steam would be used in the engine per hour. Reducing this by 10 per cent. as representing losses due to condensation in the engine cylinders, we have 18,000 lbs. per hour available for the turbine. A further reduction of 5 per cent. due to various other losses between engine and turbine makes the net amount of steam available equal to 17,100 lbs. per hour. Now the actual test figure of steam consumption of an exhaust steam turbine is about 40 lbs. per kilowatt-hour, so that the turbine should give an output of $\frac{17100}{40} = 427{\cdot}5$ k.w. This must be reduced by 5 per cent. to cover power required to drive condensing plant where cold circulating water is available (60°), giving a net output of about 400 k.w. If only hot cooling water be available (80°), 10 per cent. may be required to drive condensing plant, in which case the output will be about 380 k.w.; that is to say, at least 50 per cent. to 60 per cent. of the output of reciprocating engine is obtained from the turbine.

This figure is not by any means the very best which is ever touched for non-condensing working, but illustrates rather the minimum benefit which a well-considered installation might be expected to provide.

Condensing Engines.—In the case of condensing engines we have to consider the effects of running the engine non-condensing instead of condensing. Unless we supply more steam to the engine its output will fall under the non-condensing condition. In some cases it does not matter if the output of the engine does fall (as, for instance, when engine and turbine supply the same busbars, the output of the combined plant being, of course, always greater than that of engine only), but in other cases, as, for example, when the engine is mechanically connected to its load and the turbine electrically, it is easy to see that it may be essential that the output of the reciprocating engine should be maintained. There are therefore two broad cases of the condensing condition which may be worked out as follows :—

(*a*) ***Primary Engine Output Diminished.***

Engine	= 1,000 I.H.P. or 700 k.w.
Steam used condensing ...	= 16,000 lbs. per hour.
Output of engine only, non-condensing, on same quantity of steam	= 750 H.P. or 520 k.w.

Net output of turbine (see previous remarks) ... $\Big\} = 0{\cdot}95\left(\dfrac{16000 \times 0{\cdot}9 \times 0{\cdot}95}{40}\right)$

$= 320$ k.w.

∴ Total combined output $= 520 + 320 = 840$ k.w.

(20 per cent. more than output of primary engine alone.)

The gain of 20 per cent. is small compared with that evinced under the more usual condition of working as follows :—

(*b*) *Primary Engine Output Maintained.*

Engine ... ... = 1,000 I.H.P. or 700 k.w. as before.

Steam used condensing ... = 16,000 lbs. per hour.

Steam necessary to maintain same output of engine when running non-condensing ... = 16,000 + $33\frac{1}{3}$ per cent.

= 21,000 lbs., say.

Net output of turbine ... ... $= 0{\cdot}95\left(\dfrac{21000 \times 0{\cdot}9 \times 0{\cdot}95}{40}\right)$

$= 425$ k.w.

∴ Total combined output $= 700 + 425 = 1{,}125$ k.w.

(60 per cent. more than output of reciprocating engine alone.)

To discriminate on the score of economy among the foregoing results the steam consumptions of the combined plants require to be worked out. They are found to be :—

(*a*) With non-condensing engine ... 17·6 lbs. per k.w.-hour.
(*b*) With condensing engine under condition (*a*) ... ... 19·4 „ „
(*c*) With condensing engine under condition (*b*) ... ... 18·5 „ „

The whole of the results are summarised in the table below :—

Case.	Increase in Output.	Decrease in Over-all Steam Consumption per Kilowatt-hour.
	Per Cent.	Per Cent.
Non-condensing	60	41
Condensing; engine output diminished	20	19
Condensing; engine output maintained	60	23

These results must not be taken and applied haphazard to any engine happening to be under consideration in any capacity except that of their relation to one another. In every case the fullest calculations must be worked out for the particular conditions obtaining, both for the existing plant as well as for the turbine. The output of the engine may generally be maintained if necessary by altering the setting of the valves so as to make the cut-off later in the high-pressure cylinder. With ordinary compound engines this is the principal alteration, but with triple-expansion engines the radical alterations necessary may be so great as to render the exhaust steam scheme better abandoned. Obviously the greater the gain which the engine has been deriving from vacuum the more drastic the alterations necessary to enable it to run non-condensing. The alterations, of course, impose a greater strain on the working parts of the engine, and care must be taken to ascertain that they are sufficiently strong to stand this.

In cases where engine and turbine are supplying common busbars there is not the same necessity for upkeep of the engine output, as it is usually sufficient if the combined output reaches the required amount. The turbine must now be designed of such an output and suitable for such an engine back pressure as to permit an economical distribution of load between the engine and turbine while maintaining an exhaust pressure during average load slightly above atmosphere in order to prevent air leakage in exhaust valves and pipes.

An engine is usually rated at its most efficient load when running non-condensing, and a turbine should be installed which will pass the quantity of steam exhausted by the engine at that load with a back pressure of from 14 to 16 lbs. absolute. At this load the turbines should give an output nearly equal to that of the engine.

In such cases, where the engine and turbine are coupled to the same busbars, there will be a continuous flow of steam to the turbine proportional to the load on the engine, and as they are coupled to common busbars they are practically acting as one unit. As therefore the turbine utilises the whole of the exhaust from the engine the output of the former is always proportional to that of the engine and no governor is required for it.

In all cases, where the turbine is not coupled to the same busbars as the engine, a governor is required to maintain a constant speed on the turbine. The means by which a governor may control an exhaust steam turbine are various, and will depend upon the conditions under which the combined plant is to operate. In cases where the load on the turbine is likely to become too low for it to utilise all the engine exhaust, the governor may be arranged to operate a throttle valve on the turbine itself, an automatic relief valve being fitted in the engine exhaust to allow the surplus steam to be exhausted to atmosphere or condenser, thus keeping down the pressure in the exhaust pipe. This, however, is not good practice, the most suitable method being to arrange the governor to control directly a relief valve in the exhaust pipe, and thus maintain the exact pressure in the receiver for the

various loads on the turbine. This method has the advantage of eliminating risk of excessive back pressure on the engine when the turbine is running lightly loaded.

Little or no auxiliary gear is required by the turbine itself beyond the governor and valves controlled thereby; but under whatever conditions the turbine is installed it must always be equipped with an emergency valve to shut off steam and prevent the speed rising to a dangerous point should the load be suddenly thrown off the turbine.

Condensing Plant.—Practically all the work performed by an exhaust steam turbine being obtained from steam below atmospheric pressure, it is obvious that a good vacuum is one of the first essentials in a low-pressure installation, and the question now arises as to what is the most economical vacuum to employ, and the most suitable condensing plant for obtaining it. The question involves not only a consideration of capital outlay on condensing plant, but also of the annual expenditure and power required for the upkeep and the running of same.

A condensing plant and vacuum must be chosen which will enable the turbine to obtain the maximum amount of energy from the steam available, consistent with capital outlay and running costs, as either of these might easily reach such a high figure as largely to neutralise the gain obtained by the utilisation of the exhaust steam.

The actual saving in steam consumption between a 27-in. and 28-in. vacuum is very considerable, but in many cases the extra cost and power required to obtain the last inch of vacuum outweigh all the saving to be obtained thereby. It may, in fact, be broadly stated that, excepting under the most favourable conditions, little material advantage is gained by a vacuum much higher than 27 to 27½ in.

Where the whole of the exhaust from the engine is to be used by the turbine the capacity of condenser may usually be determined by the steam consumption of the engine when running fully loaded, plus a small allowance for back pressure due to the turbine.

Where the engine has been running condensing, the question arises as to whether the existing condenser will serve for the combined plant; and this may often be a determining factor in deciding whether an exhaust steam turbine is worth installing at all.

Observation of the variation of vacuum at different loads and the ratio of temperature of cooling water discharge to air-pump discharge will usually provide sufficient data for determining whether the existing condenser will be suitable, or whether it could be made suitable with slight alterations. An ideal condenser is one which will discharge its cooling water at the same temperature as that of evaporation at the pressure of the exhaust system, but this is seldom, if ever, realised in practice. A first-class jet condenser seldom approaches closer than 15° F., and a surface condenser would have a greater difference still. If, however, a greater difference than 40° to 50° is found to exist in the old surface condenser, it will probably be found that its capacity and efficiency may be improved by rearranging the baffles to provide a better distribution of steam among the tubes; while the removal of

a few tubes to provide passages among the remainder might also be found advantageous. Further improved results may often be obtained by making the water pass through a less number of tubes at a time and thus increasing its velocity and number of passes. This would require a little more power on the pump, but it can usually be obtained without difficulty by increasing the speed. The capacity of an old condenser might also be fairly cheaply increased by supplementing it with a small ejector condenser or a Parsons augmenter.

In cases where the old condenser cannot be used, and, of course, where the engine has been running non-condensing, a new condensing plant must be installed. This would be of a modern type guaranteed by the makers to maintain the required vacuum under the conditions stated. In the specification therefor it would be necessary to inform tenderers as to maximum quantity of steam to be dealt with; temperature, nature, and quantity of cooling water available; whether cooling towers are used; relative heights of cooling water level, condenser level, and discharge level; and also the nature of power available for drive. Beyond supplying this information, the problem before the installation engineer merely resolves itself into a decision as to the most suitable type of condenser to install.

The choice lies broadly between two types, namely, surface or jet condensers. Owing to the great cost of surface as compared with jet condensers, they should only be installed where the necessity of using condensed steam for boiler feed makes it imperative.

In the case of jet condensers there are three types to be considered—viz., the plain or centrifugal jet, the barometric jet, and the ejector condenser.

In comparing the three types it will be found that the barometric jet and also the ejector condenser (whether working barometrically or otherwise) generally require considerably more water than the ordinary and centrifugal types and should not therefore be installed where water is scarce. The barometric condenser, in addition to the small power required for pumping, possesses the advantage that under no circumstances can the condenser be flooded or water enter the exhaust pipe (an occurrence which is somewhat liable to occur in low-level working unless special provision is made); but a great disadvantage of this condenser is that the fall of pressure in the long exhaust pipe and the entrainer necessary to drain it may be very considerable, while a centrifugal jet condenser can be placed at the turbine with little or no exhaust piping at all, and should therefore always have preference unless conditions make the advantages of barometric working well marked. Further, it would seldom pay to install barometric condensers where cooling towers are necessary, as an additional pump would be required to raise the discharge water to the towers.

First cost is certainly in favour of the ejector condenser owing to the absence of air pumps, but this is offset by the fact that with this condenser a small air leakage usually causes a great loss of vacuum, and also by the larger quantity of water required by it.

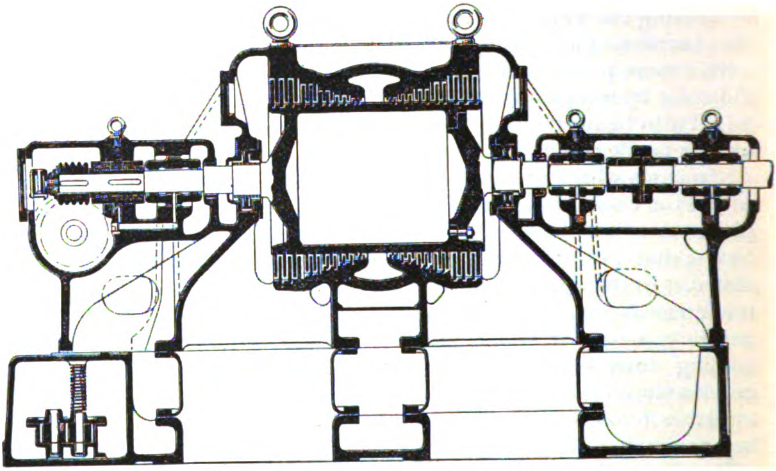


FIG. 2.—Westinghouse Parsons Exhaust Steam Turbine.

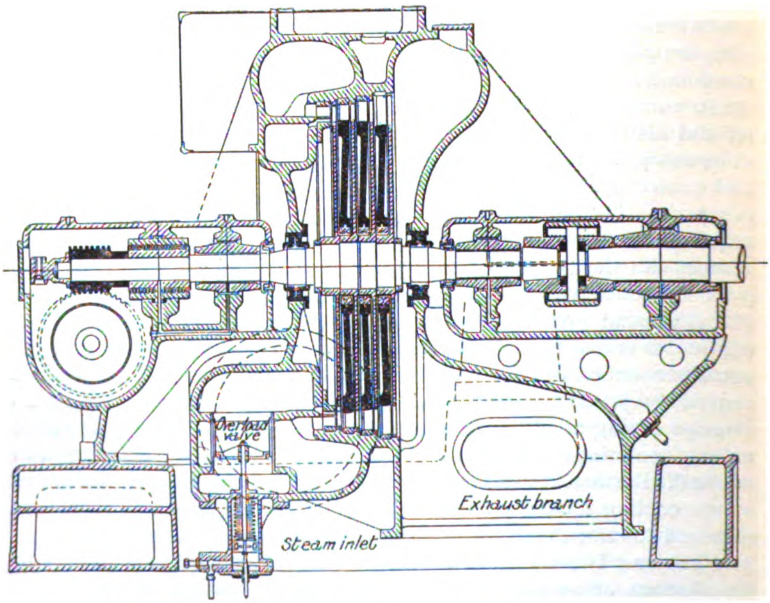


FIG. 3.—Westinghouse Rateau Exhaust Steam Turbine.

To summarise, a surface condenser should not be installed unless the condensed steam must be returned to the boilers. Preference given to centrifugal jet condensers is certain to be a paying investment unless the conditions particularly favour barometric working.

Constructional Features of Exhaust Steam Turbines.—Exhaust steam turbines lend themselves to much more simple design and construction than do turbines of the high-pressure complete expansion type. In the exhaust steam turbine, there being only half the pressure drop, only half the number of rows of blades or bucket-wheels are necessary, while the risk of distortion and other troubles due to high steam temperatures is practically nil. The volume of steam being much greater for a given output, much more substantial blade dimensions are readily obtained, further permitting the turbine to be designed for operation at comparatively low speeds; and as the pressure drop between stages is low, a safer margin of clearance may be allowed without greatly impairing the efficiency of the turbine. It will therefore be evident that the exhaust steam turbine is naturally an exceptionally strong and substantial machine, the reliability of which may be absolutely depended upon.

A low-pressure turbine of the pure reaction type is shown in Fig. 2, which is a section of two Westinghouse Parsons turbines of 1,250 k.w. running in the exhaust steam station at Messrs. Samuelson's Newport Works, Middlesborough. The turbine is designed on the well-known double-flow principle, by which the end thrust and therefore the necessity of dummy pistons is eliminated, thereby making a machine of great strength and stability. The turbine is designed to work on the exhaust from blowing engines at atmospheric pressure and 50° F. superheat. With a vacuum of 28·8 in., it is guaranteed for full load at a steam consumption not exceeding 27 lbs. per kilowatt-hour.

An example of the impulse type of exhaust steam turbine is shown in Fig. 3, which is a section through one of two 2,000-k.w. Rateau turbines manufactured by the British Westinghouse Company to the order of Mr. P. J. Mitchell for the Dominion Iron and Steel Company, of Canada. In this type of turbine the expansion takes place in stages, each of which consists of a diaphragm fixed in the cylinder and a moving wheel. The actual expansion of the steam takes place in the fixed vanes only, from which it is projected at a high velocity on to the moving vanes on the periphery of the wheels. As no expansion takes place in the moving vanes, there is no difference of pressure between inlet and outlet sides of same, and consequently there is no tendency for the steam to leak past the top of the blades, and liberal clearances may therefore be employed.

Instead of an emergency valve to shut off the steam from the turbine in the event of its running away, a vacuum breaking valve is provided which is operated by a trip from the safety governor, while at the same time the governor valve is released and closed by its own weight.

An interesting example of a mixed-pressure turbine of the impulse type is shown in Fig. 4, which is a diagrammatic view of a three-stage

B.T.H.-Curtis turbine having 1 low-pressure and 2 high-pressure wheels. It will be seen that the low-pressure supply is admitted to a belt surrounding the centre of the casing and communicating with the nozzles discharging on to the second stage-wheel. These low-pressure nozzles do not extend round the entire circumference, a portion of this being occupied by nozzles receiving steam from the first stage of the high-pressure wheel. It will therefore be seen that the two supplies will not mix until they have done work in the second stage, and that the low-pressure admission is quite free from interference by the high-pressure steam. By this arrangement of a special

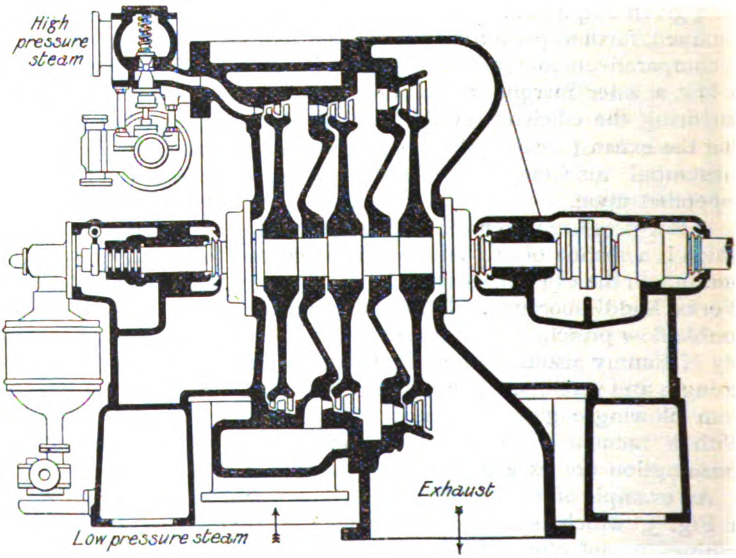


FIG. 5.—B.T.H. Curtis Mixed-pressure Turbine.

high-pressure stage, it is possible to obtain efficiencies practically equal to that of an ordinary high-pressure turbine, more especially as the second high-pressure nozzles can be designed to suit the high-pressure conditions without any reference to the low-pressure requirements.

Installations.—Space does not permit the description of many installations carried out, but information of this kind can be readily found by reference to the technical press and the journals of proceedings of other institutions.* One installation may be described, however, as typical of exhaust steam utilisation with heat accumulators on intermittent steam supply. This plant is installed at the Hallside works of the Steel Company of Scotland, and is shown in Fig. 5. The engines exhausting into the accumulator consist of one cogging engine,

* *The Electrical Review*, vol. 63, p. 889; vol. 67, p. 447; *Journal of the Institution of Electrical Engineers*, vol. 43, p. 752, 1909.

one finishing main engine, two small mill engines, and two steam hammers, supplying in all 41,000 lbs. of steam per hour. The turbines installed are each of 450-k.w. capacity.

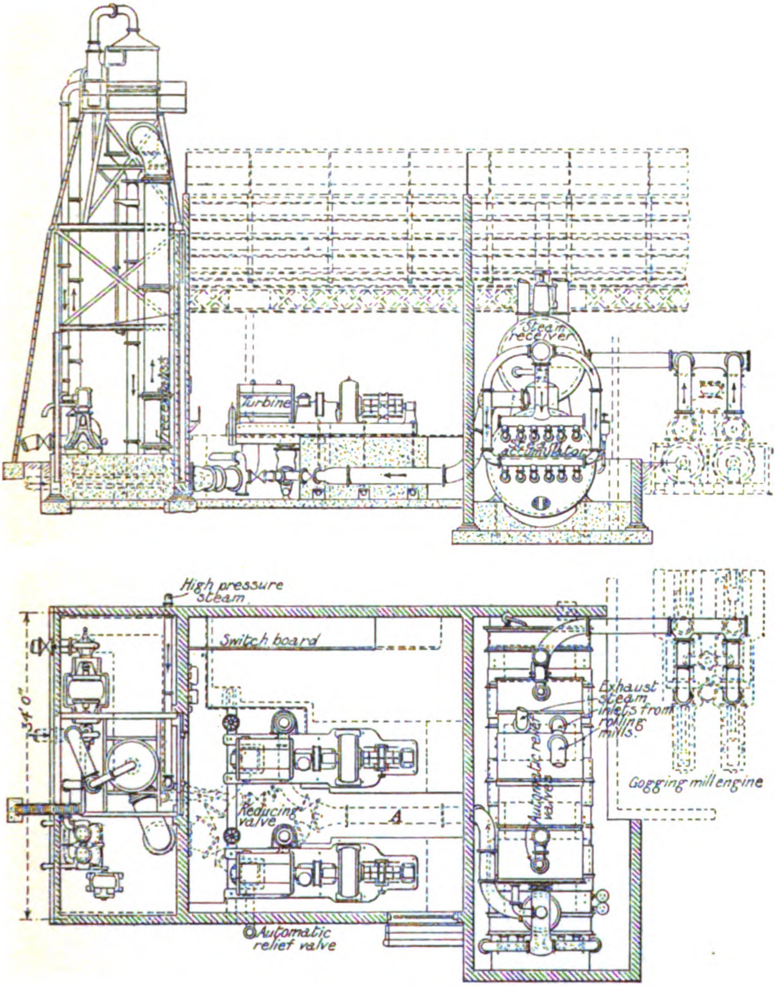


FIG. 5.—Exhaust Steam Turbine.

The accumulator is surmounted by a receiver which breaks the violent shocks of the exhaust steam. After leaving the accumulator the steam passes through a 21-in. main to the inlet valves of the turbines. A high-pressure main is brought into the engine-room at the opposite

end of this pipe, and is fitted with a special reducing valve for supplying reduced pressure live steam to the turbine when the main engines are standing for roll changing, etc.

The turbine exhausts to a barometric jet condenser capable of maintaining a 90 per cent. vacuum. With this vacuum and atmospheric inlet pressure the efficiency compared with the theoretical duty of steam expanded between these limits of pressure is 65 per cent.

The widest field for development has at present revealed itself in industries where steam is running to waste uncondensed, but the authors have sought to show that at certain times and under certain conditions, and particularly with mixed-pressure turbines, there are cases in almost every industry requiring power in large quantities where the low-pressure turbine would present a thoroughly sound proposition to the owner.

ORGANISATION AND THE REDUCTION OF MANUFACTURING COSTS.

By A. R. STELLING, Dipl. Ing., Student.

(*Abstract of paper read before the* MANCHESTER STUDENTS' SECTION, *December* 13, 1910.)

The object of the paper is to assert the scientific principles of organisation in manufacture without going into any detailed routine. The three essentials of organisation will be discussed and their application to modern works management will be indicated.

Record-keeping.—The first essential is accurate and systematic record-keeping. The importance of record-keeping cannot be too highly estimated, and each item should be carefully thought out and supervised. It is only recently that systematic comprehensive record-keeping has received the attention it deserves, and this has been brought about by the bitter experience of those who have had to contend with the faulty records of their precursors.

If we are to assume the principle that all work done in each department ought to be of a productive or useful nature, then records should be kept, because, if the work is useful, it is worth recording; if useless, then records assist its elimination. This is the fundamental principle of any successful organisation or time-saving.

Inter-departmental Relations.—The second essential is the regulation of inter-departmental relations. Each department should be a complete unit, and as far as possible independent of other departments. It should be in a position to conduct its own correspondence, and should be supplied, in black and white, with information sufficient for its own uninterrupted working. The various office staffs should particularly be kept *au fait* with the latest shop practice.

Distribution of Information.—The third essential is speed in obtaining and transmitting information. Each department must be educated to have confidence that all necessary information will be handed in automatically as soon as ever possible. To obtain this organisation of speed it is better, given a certain number of men, to work them in parallel than in series, as is illustrated by the following diagrams.

These are two diagrams analysing the passage of orders through the departments concerned. I have taken as an instance the handling

of an order for a large contract, including electrical machinery. The diagrams are not complete, but will serve to illustrate my point of rapidity in handling information.

Fig. 1. Orders are received by A, who extracts particulars of the motors and generators required and passes these to the designer D. Driven or driving units are extracted and requisitioned from the buying

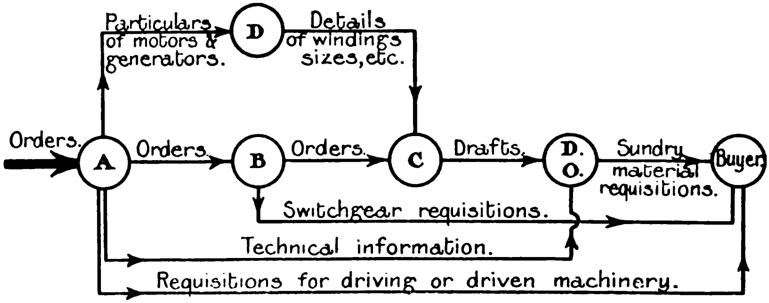


FIG. 1.

department. Technical information is passed to the drawing office (D O) and the original papers are passed to B. B extracts switchgear particulars, requisitions the buying department, and passes the papers to C. C extracts particulars for invoicing, and with the details which come from D writes out the draft order for D O and shops. It is

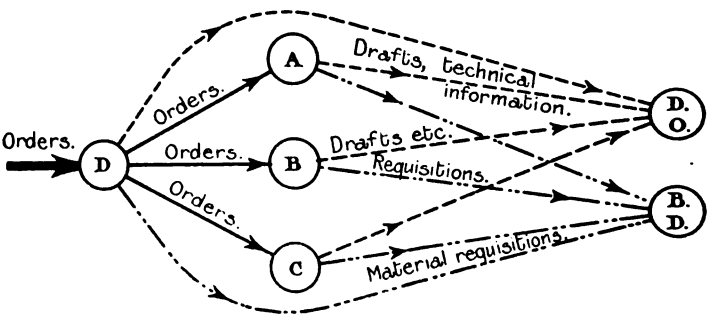


FIG. 2.

obvious that, however well organised each individual's routine may be, the system is slow in its working.

Fig. 2 shows a more expeditious system, but with the same number of men employed. Orders go to the chief engineer D. He retains such work as he wishes to conduct himself and passes the orders to his three assistants. Each deals with an order completely, and thus orders reach the shops practically the same day that they arrive in the office.

Diagrammatic analysis is most useful and practical, and can be applied both to theoretical and practical considerations. In actual diagrams coloured lines should be used. Applying these three essentials to the actual manufacture, we find that they form the basis of successful works management. Modern works management must be highly organised; it must not depend solely upon the efforts of individuals, it must possess definite routine in order to obtain reductions in the cost of production and prompt deliveries. There is more room for the application of exact principles to works management than is at first apparent; I propose briefly to indicate the fundamental ideas of an organised control of manufacture and of its cost.

Stock Orders.—The first object to be aimed at is standardisation and working to stock orders. It will be obvious to all manufacturing engineers that small work can only be profitable when manufactured in quantities. As many different items as possible should be thus tooled and stored in a "finished part stores." By the careful organisation of these stores economy may be achieved in the number of parts stocked, and yet a continuous supply for assembly to orders may be maintained; these stores materially assist the planning of work in advance, especially on standard products. This advance planning is too often entirely neglected.

Standing Charges.—Standing charges play a great part in the cost of production, and their regulation is discussed at length in the paper. Such charges as the wages of foremen, inspectors, works' office staff, and the tool-room labour and equipment should not be cut down too finely, for upon these departments falls the onus of remunerative production.

No less important than the supervision of the actual manufacture is the organisation of the cost keeping and cost control; here the three essentials come very noticeably to the fore. The costing of the labour charges, which should unquestionably be under the direct supervision of the works manager, is best achieved with the use of job or time cards. These should be handled as little as possible by the workmen, and the clerk responsible for them should prepare them for the wages department. Costs for stock orders or shop orders should be completed with all possible speed, and the manager must be kept in touch with all current costs. It is a mistake to supply figures too long after the completion of an order, because special circumstances or difficulties are then apt to be forgotten. Costs require not only to be recorded, but controlled, both before and after operations.

Cost Control before Operation.—Costs are controlled prior to the issue of work to the shops by determining a piecework price or bonus time. Cards are issued from the works office to the foremen detailing operations and time allowed. These cards assist the planning of work, as well as the control of cost. If no time can be pre-determined, the card when returned will show the time accurately noted, with a view to fixing a time for later orders. Times for new designs can be easily determined from cost charts. These are graphs, straight lines or

curves, plotting operating times against constants derived from the nature of the operation and the amount of tooled surface.

By extracting the times for all operations upon a range of finished products, a curve of total costs can be plotted. For example, Fig. 3 is a curve of costs of a line of direct-current motors plotted against the motor size in horse-power at 1,000 revolutions.

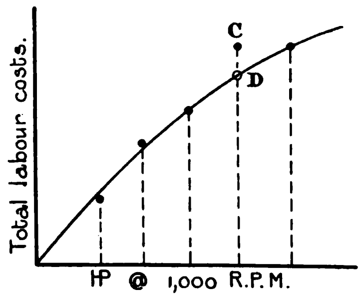


FIG. 3.

Point C lies too high, therefore by investigation of individual items a judicious alteration of mechanical design may be made to bring point C to its proper position on the curve. Such cost charts are most useful in costing new designs.

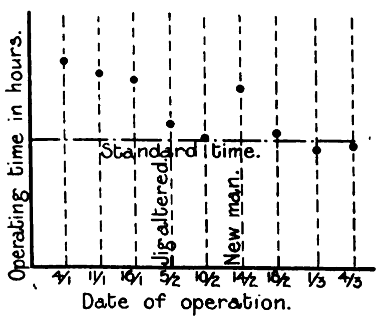


FIG. 4.

Cost Control after Operation.—Control after operation is the record-keeping of actual operating times for different pieces of work. Graphs are best used here, but to be of use accurate returns from the shops must be insisted on, together with remarks as to causes of lost time, use of jigs, etc. Particular attention must be paid to the returns concerning day-work jobs with a view to fixing a bonus time at an early date. A specimen graph is shown in Fig. 4.

Application of Scientific Principles.—The essentials of organisation and management may be summed up as the application of scientific principles to organisation and control. The works office organised on the lines indicated would contain more skilled employees than are usually found in such an office, but the extra expense is justified by an increase of efficiency and by a decrease of waste. A system worked half-heartedly is not worth having; it only distracts attention from one fault while half-curing another.

Finally, the finest system is liable to come to grief on the rocks of personal and departmental friction; therefore a manager's first aim must be to choose his men and handle them so that harmony, enthusiasm, and mutual assistance obtain in the perfection of their organisation.

THE PRESENT POSITION OF ELECTRIC TRACTION ON MAIN LINES IN EUROPE.

By J. B. SPARKS, Student.

(*Abstract of paper read before the* STUDENTS' SECTION *on April* 12, 1911.)

The object of this paper is to present a record of the present position of electric traction in Europe. Switzerland is considered first, as the reports of the Government Commission are referred to in some detail.

SWITZERLAND.

About 23 miles of main line, 95 miles of standard-gauge branch lines, and 655 miles of narrow-gauge and rack-and-pinion lines are already worked electrically. There is no coal in the country, but water-power is plentiful. The only electric line of the Swiss Federal System, which, including the recently nationalised St. Gotthard railway, comprises 1,850 miles of line, is the 14-mile Brigue-Iselle single-track section of the Simplon tunnel line, worked at 3,000 volts, 16 cycles, 3-phase. The equipment will shortly be extended from Iselle to Domo d'Ossola, and there is a scheme for connecting Domo d'Ossola to Locarno, to join the Simplon and St. Gotthard railways. In 1904 a Government Commission was appointed to study the question, and three reports have been issued. The first deals with the probable power requirements of the whole Federal system, and concludes that the average daily consumption would be 2,400,000 H.P.-hours at the generating stations, corresponding to a continuous output over the 24 hours of 100,000 H.P. The ratio of maximum to average demand at a transformer station is estimated at from 7 to 12. As even the largest power station must have a capacity of at least five times the average demand of the districts served, the total capacity of the water-power stations is estimated at 500,000 E.H.P. The second report discusses traffic questions, and concludes that though lighter and more frequent trains composed of motor coaches will be used for local and general express service, it will be necessary to retain the long heavy trains hauled by locomotives for the international and goods services. The third report summarises the arguments as to the most suitable frequency for single-phase railways, which resulted in the Federal authorities fixing 15 cycles per second as the standard frequency for railways in Switzerland. Dr. Wyssling, the Recorder of the Commission, has informed the

author that the fourth report, to be published shortly, will be a restatement of the conclusions given in his paper read at the July, 1910, meeting of the International Railway Congress at Bern. These are in favour of the single-phase system, with a contact-wire pressure of 15,000 volts and a frequency of 15 cycles. Measurements carried out by the Commission on single-phase equipments show the following efficiencies: Trains, 70 to 75 per cent.; contact-wire and rail return, 90 to 94 per cent.; transformer stations, 80 to 82 per cent.; and high-tension transmission line, 90 per cent., or an over-all efficiency of 45 to 52 per cent. For direct-current systems the over-all efficiency was 45 to 64 per cent., and for 3-phase systems, 39 to 42 per cent. From rough estimates by the Commission of the cost of converting the St. Gotthard Railway, the direct-current system gave a capital cost so high as to make it impracticable, and the 3-phase equipment came out some 8 per cent. higher than the single-phase equipment, the cost of which was estimated at £2,700,000. The running costs were estimated at some 10 per cent. less than the present costs with steam traction.

The Bernese Alpine Railway Company is constructing a new main line of considerable importance between Spiez and Brigue. At present only the 8·7-mile section between Spiez and Frutigen is working, but the Company inform the author that the complete line, measuring 37 miles, inclusive of the 9-mile Loetschberg tunnel, will be working electrically by May, 1913. The system adopted is 15,000 volts, 15 cycles, single-phase. The total cost of the line will be some £3,000,000. The company is heavily subsidised by the State, who will eventually take over the railway. Foremost among the other standard-gauge lines not owned by the Federal authorities is the famous Burgdorf-Thun 3-phase line, 25 miles long, and worked at 750 volts, 40 cycles. The Seetal Railway, 34 miles long, is equipped on the single-phase system at 5,000 volts, 25 cycles, and the 12-mile Martigny-Orsieres branch line, also single-phase, at 8,000 volts, 15 cycles. The Rhætian Railway Company, which owns an important system of narrow-gauge lines in the Engadine, is converting all its lines to single-phase working at 10,000 volts, 16⅔ cycles, the power being supplied to motor-generator sub-stations at 25,000 volts, 50 cycles, 3-phase.

Germany.

In the North and North-East of Germany coal is plentiful and water-power scarce, but the reverse conditions prevail in the South. The Prussian authorities control over 64 per cent. of the whole system, and have been carrying out experiments since 1903. The suburban lines connecting Hamburg, Altona, Blankenese, and Ohlsdorf have been working successfully on the single-phase system, at 6,000 volts, 25 cycles, since 1906. As an experiment in heavy main-line work, the 16-mile length of double track between Dessau and Bitterfeld was equipped on the single-phase system at 10,000 volts, 15 cycles, and the results have been so successful that the equipment is to be extended

shortly to Magdeburg, Leipzig, and Halle. The length of route (double-track) from Magdeburg to Leipzig is 73 miles, and from Leipzig to Halle 22 miles. Current is supplied from a steam station burning lignite. A further system of lines in Silesia is also shortly to be equipped on the same system. The line connects Görlitz with Königzelt, and with branches comprises 180 miles of line. The Bavarian authorities issued a report in 1908 recommending electrification on the single-phase system, and the main line between Salzburg and Freilassing, with a branch to Reichenhall, comprising 28 miles of line, are now being equipped on the single-phase system at 10,000 volts, 15 cycles. A short section of a new main line between Munich and Partenkirchen is also being equipped for electrical working, and a water-power station is being erected large enough to supply the whole line. Following the example of Prussia and Bavaria, the Baden authorities have also adopted the single-phase system at 10,000 volts, 15 cycles. A 31-mile section of main line between Basle and Zell known as the Wiesenthal Railway is now being equipped. Current is to be supplied to the sub-stations at 7,000 volts, 50 cycles, 3-phase, from a water-power station near Basle.

Austria and Hungary.

In the region north of the Danube there is practically no water-power, but there is good coal, whereas in the south there is no coal but abundant water-power. The Austrian State Railway authorities appointed a Commission in 1906. The investigations have been limited to the railways south of the Danube, but detail plans have been prepared for some 620 miles of line. The Trieste-Opcina line including five single-track tunnels with a total length of 29 miles is to be electrified shortly on the single-phase system at 10,000 volts, 15 cycles, and this system is also favoured for the other lines. including the famous Arlberg Railway from Innsbruck to Lindau. The Austrian South Railway Company intend to electrify shortly the lines from Kufstein to Ala and from Marburg to Franzensfeste, and favour the 3-phase system on account of the very heavy gradients. The Mittenwald Company is constructing a new main line 63 miles long from Innsbruck to Reutte, *viâ* Garmisch-Partenkirchen, where it will connect with the new Bavarian line from Munich. The single-phase system at 10,000 volts, 15 cycles is to be employed. There are already many branch and interurban lines operated electrically, particulars of which are given in the original paper.

The Hungarian authorities have also appointed a Commission to study the matter and much work has been done. The suburban line connecting Buda-Pest with Vacz and Gödöllo, 36 miles long, is now being equipped on the single-phase system at 10,000 volts, 15 cycles. Plans have been prepared for short lengths of main line running out of Prague, and for several other lines, for some of which the authorities ropose to adopt the 3-phase system.

FRANCE.

Owing to the congested nature of the traffic round Paris, the State has decided to assist in the conversion of the inner belt line of the Chemins de fer de Ceinture, and electric traction will also be introduced shortly on a section of the Ouest (State) Railway. The Midi Company are equipping a 70-mile section of main line between Pau and Montrejeau, and also branch lines comprising about 175 miles in all. The single-phase system at 12,000 volts, 16⅔ cycles has been adopted. The sections between Montrejeau and Toulouse and between Pau and Bayonne will also be converted shortly. New branch lines to be operated electrically are also being constructed. The short length of main line of the Orleans Company between Juvisy and the Quai d'Orsay station in Paris has been working electrically on the direct-current system with a third rail at 600 volts for ten years. The Paris-Lyon-Mediteranée Company is experimenting with a locomotive of the Auvert-Ferrand pattern in which single-phase current is transformed to direct-current on the locomotive, and intends to electrify the main line between Cannes and Ventimiglia.

ITALY.

Practically all the railways in this country are owned by the State. Coal is scarce but water-power is plentiful. The lines connecting Milan, Gallarate, Varese, and Porto Ceresio have been working on the direct-current system at 600 volts for many years. The 70-mile Valtellina Railway connecting Sondrio with Lecco and Chiavenna, operated at 3,000 volts, 15 cycles, 3-phase, has proved so successful that the authorities decided to electrify eleven further sections of main line aggregating 190 miles, and two of these sections are now being equipped on the same system—namely, the 12-mile line from Genoa to Busalla and the 12-mile line from Modane to Bardonecchia. The latter equipment is of particular interest as an attempt will be made to prevent the heavy peak loads from reaching the generating station by installing flywheel motor-generators at the sub-station. Each of the three 2,000-k.v.a. motor-generators will have a 40-ton flywheel, 12 ft. in diameter, running at 500 revs. per minute, and a commutator machine connected in cascade with the motor will reduce the speed automatically. Signor Verola, Chief Electrical Engineer to the State Railways, has stated that the single-phase system may be adopted for some of the other sections. Two or three branch lines are already working on the single-phase system at 6,000 volts, 25 cycles.

SWEDEN.

There is abundant water-power in this country, and the State authorities, after much experimenting, have adopted the single-phase system at 15,000 volts, 15 cycles, for their lines. An 80-mile main line section in the extreme north from Kiruna to Riksgränsen is now being equipped, and is to be complete in 1914. Power will be generated

single-phase and transmitted to transformer sub-stations at 80,000 volts. Plans have also been prepared for the conversion of the whole network of lines south of Stockholm, current for which will be taken from five water-power stations.

NORWAY.

Some 30 miles of line near Telemarken constructed last year in connection with the extensive manufacture of nitrates and calcium carbide in that district by electrical processes, are now being converted to single-phase traction at 10,000 volts, 16⅔ cycles. Power will be supplied 3-phase to motor-generator sub-stations. The 33-mile line connecting Christiana with Drammen is to be converted shortly, and later the important line from Christiana to Bergen.

GREAT BRITAIN.

The important direct-current branch lines in the north and the suburban lines of London are well known. The London, Brighton and South Coast Railway has now 62 miles of track equipped on the single-phase system at 6,700 volts, 25 cycles, and the early conversion of the main line to Brighton is probable. The 10-mile line between Lancaster, Morecambe and Heysham, of the Midland Railway, is worked at 6,600 volts, 25 cycles.

OTHER COUNTRIES.

The paper also dealt with the proposals for main-line electrification in Denmark, Russia, Spain, and Holland, and gave particulars of short lines already working electrically in the last two countries. Interesting technical details of the many lines mentioned above were given, and specially prepared maps showing their position were exhibited as lantern slides. Particulars and illustrations of the most recent designs of locomotives including some with single-phase Deri motors of 800-H.P. capacity on the one-hour rating were also given.

Proceedings of the Thirty-ninth Annual General Meeting of the Institution of Electrical Engineers, held on Thursday, May 25, 1911, at 4.30 p.m.—Mr. S. Z. de Ferranti, President, in the chair.

Messrs. H. H. Johnson and W. Clark were appointed scrutineers of the ballot.

The Chairman then proceeded to read the Annual Report.

REPORT OF THE COUNCIL FOR PRESENTATION TO THE ANNUAL GENERAL MEETING OF 26TH MAY, 1911.

At this, the thirty-ninth Annual General Meeting of the Institution of Electrical Engineers, the Council present to the Members their Report for the year 1910–11.

Growth of the Institution.

Since the last Annual General Meeting applications for admission into the Institution have been received from 502 persons, of whom 20 have been elected as Members, 193 as Associate Members, 32 as Associates, and 221 as Students.

100 Foreign Members, 58 Associate Members, and 14 Associates have been transferred to the class of Members, 12 Associates and 111 Students to the class of Associate Members, and 14 Students to the class of Associates.

The changes in the List of Members since the last Annual General Meeting are shown in the following table :—

	May, 1910.	May, 1911.
Honorary Members	7	7
Members	1,172	1,333
Associate Members	2,628	2,811
Associates	939	906
Students	1,368	1,286
Foreign Members	104	—
Total	6,218	6,343

Members Deceased.

Among well-known members who have died since the last Annual General Meeting are Sir John Aird, Bart., Mr. Gustav Byng, Mr. B. T. Ffinch, C.I.E., Mr. George Flett, Sir W. B. Gurdon, C.B., K.C.M.G., Sir J. Clifton Robinson, and Mr. J. Wetzler.

The complete list of those who have died during the past year is as follows:—

Members.

Peter Albertine.
Thomas Andrews.
Gustav Binswanger-Byng.
Alfred Colson.
George E. Dering.
Samuel S. Dickenson.
Benjamin Traill Ffinch, C.I.E.
John William Fletcher.
James Graves.
H. Graham Harris.
Victor A. H. McCowen.
James Hardie MacLean.
Sir James Clifton Robinson.
John Ruffell Salter.
Jacob Stöttner.
William I. Taylor.
Joseph Wetzler.

Associate Members.

James R. Barr.
Percy Rhodes Cobb.
Eustace Jonathan Down.
Gilbert Holt Green.
William Middleton.
Alfred Lovell Phillips.
Arthur Taylor.

Associates.

Sir John Aird, Bart.
George Chatterton, M.A.
George Flett.
Robert Gilmour.
The Right Hon. Sir William Brampton Gurdon, C.B., K.C.M.G.
John Murray Hincks.
William Thomas Hoal.
Douglas Sheppard.

Students.

Arnold Francis K. Allbrook.
Thomas Carey Dunne.
Herbert Dieudonné Gervers.
Vasudeo S. Padhye.

Foreign Members.

Professor George F. Barker.
Professor Paulo Benjamin Cabral.
General Thomas T. Eckert.
Senkichi Kanda.

Biographical notices of the deceased members will be found in the *Journal.*

Resignations.

11 Members, 25 Associate Members, 28 Associates, 51 Students, and 1 Foreign Member have resigned since the last Annual General Meeting.

Meetings and Papers.

During the past year 17 General Meetings, 1 Special General Meeting, and 21 Council Meetings have been held. The usual Standing Committees have met regularly throughout the year, and several Occasional Committees appointed by the Council for the consideration of special matters have also met, the total number of Committee Meetings held during the year being 109.

There have been 50 meetings of Local Sections, viz., 7 at Birmingham, 7 at Dublin, 6 at Glasgow, 11 at Manchester, 12 at Newcastle, and 7 at Leeds and Sheffield.

The Annual Dinner of the Institution took place at the Hotel Cecil, London, on 2nd February, 1911. A report of the proceedings will be found in the *Journal*, vol. 46, p. 497.

Annual Dinners and other social functions were held at Birmingham, Dublin, Glasgow, Leeds, Manchester, and Newcastle, which were well attended by members and guests, and at which several Members of Council were present.

The following is the list of papers for the Session, with the names of the authors and the places where read :—

Title.	Author.	Where Read.
Inaugural Address of President.	S. Z. de Ferranti.	London.
Chairman's Address.	M. J. Railing.	Birmingham.
Chairman's Address.	W. Tatlow.	Dublin.
Chairman's Address.	S. Mavor.	Glasgow.
Chairman's Address.	T. Harding Churton.	Leeds.
Chairman's Address.	J. S. Peck.	Manchester.
Chairman's Address.	C. Faraday Proctor.	Newcastle.
"Automatic Telephone Exchange Systems."	W. Aitken, Member.	London.
"Some Considerations relating to the Parallel Working of Alternators."	J. R. Barr, Associate Member.	Glasgow.
"A Power Company's Testing Department."	E. Fawssett, Associate Member.	Newcastle.
"Merz-Price Protective Gear and other Discriminative Apparatus for Alternating-current Circuits."	K. Faye-Hansen and G. Harlow, Associate Members.	Birmingham and Manchester.
"Measurement of Relative Angular Displacement in Synchronous Machines."	W. W. Firth.	Newcastle.
"Chemical Action in Windings of High-voltage Machines."	A. P. M. Fleming and R. Johnson, Associate Members.	Manchester.
"Electric Heating as applied to Cooking Apparatus."	Harold Gray, Associate Member.	Manchester.

TITLE.	AUTHOR.	WHERE READ.
"The Magnetic Properties of Iron and its Alloys in Intense Fields."	Sir R. A. HADFIELD, F.R.S., and Prof. B. HOPKINSON, F.R.S., Members.	London.
"Street Lighting by Modern Electric Lamps."	H. T. HARRISON, Member.	London, Birmingham, and Manchester.
"The Driving of Winding Engines by Induction Motors."	H. J. S. HEATHER, Member.	London.
"Static Sub-station Design."	P. V. HUNTER, Associate Member.	Newcastle.
"Extra-high-pressure Transmission Lines."	R. B. MATTHEWS and C. T. WILKINSON, Associate Members.	London, Manchester, Newcastle, and Yorkshire.
"The Heating of Cables with Current."	S. W. MELSOM, Associate Member, and H. C. BOOTH.	London.
"The Electrical Undertaking of the Birmingham Tame and Rea District Drainage Board."	L. F. MOUNTFORT, Associate Member.	Birmingham and Manchester.
"Practical Aspects of Printing Telegraphy."	DONALD MURRAY, Member.	London.
"Submarine Cables for Long-distance Telephone Circuits."	Major W. A. J. O'MEARA, C.M.G., Member.	London.
"Electricity Meters with Notes on Meter Testing."	H. A. RATCLIFF and A. E. MOORE, Associate Members.	London and Manchester.
"Control of Electric Winding and Hoisting Engines."	Dr. E. ROSENBERG, Member.	Manchester.
"The Irregularities in the Rotating Field of the Polyphase Induction Motor."	C. F. SMITH, Member.	Manchester.
"The Non-salient Pole Turbo-alternator and its Characteristics."	STANLEY P. SMITH, Associate Member.	Birmingham.
"Battery Economics and Battery Discharge Arrangements."	A. M. TAYLOR, Member.	London and Birmingham.
Wireless Telegraph in Relation to Interferences and Perturbations."	J. E. TAYLOR, Associate Member.	London and Newcastle.
Modern Long-distance Transmission of Electrical Energy."	W. T. TAYLOR, Member.	London, Manchester, Newcastle, and Yorkshire.

Title.	Author.	Where Read.
"The Laying and Maintenance of Transmission Cables."	C. Vernier, Associate Member.	London, Glasgow and Newcastle.

In addition to the above-mentioned papers read at meetings the following have been accepted for printing in the *Journal*:—

Title.	Author.
"The 'Benkö' Primary Battery and its Applications."	W. R. Cooper, Member.
"The Theory of the Static Balancer."	C. C. Hawkins, Member.
"A Graphical Treatment of the Skin Effect."	Prof. A. Hay, Member.
"Inherent Speed Regulation of the Direct-current Shunt Motor."	E. W. Short, Associate Member.
"Electric Winding."	G. Stjernberg.
"The Testing of Transformer Iron."	L. W. Wild, Member.

Scholarships.

The Council have awarded Salomons Scholarships of the value of £50 each to Richard Michael Clark, of University College, and to Edward M. Teare, of the Finsbury Technical College; and a David Hughes Scholarship of the value of £50 to Francis Lewes Otter, of the Central Technical College.

Premiums.

The list of premiums for papers has been revised and in future premiums will be awarded in accordance with the list shown below. In considering papers, those published in the *Journal* without being read at a meeting will not, after this year, be considered separately from those read at meetings.

Name.	Subject.	Value. £
Institution	Any	25
Ayrton	Practical Applications of Electricity	10
Fahie	Telegraphs and Telephones ...	10
John Hopkinson ...	Design and Construction of Electrical Machinery	10
Kelvin	Scientific Research	10
Paris Electrical Exhibition... ...	Any	10
Webber	Military and Naval Applications of Electricity	10
Extra Premium ...	Any	5

The following premiums for papers have been awarded by the Council this year. In accordance with precedent, in deciding upon these awards the Council have not taken into account papers contributed by present members of Council.

The INSTITUTION PREMIUM, value £25,

to Sir R. A. Hadfield, F.R.S., and Professor B. Hopkinson, F.R.S., for their paper, "The Magnetic Properties of Iron and its Alloys in Intense Fields."

The AYRTON PREMIUM, value £10,

to Mr. H. T. Harrison, for his paper, "Street Lighting by Modern Electric Lamps."

The FAHIE PREMIUM, value £10,

to Mr. Donald Murray, for his paper, "Practical Aspects of Printing Telegraphy."

The JOHN HOPKINSON PREMIUM, value £10,

to Messrs. A. P. M. Fleming and R. Johnson, for their paper, "Chemical Action in Windings of High-voltage Machines."

The PARIS ELECTRICAL EXHIBITION PREMIUM, value £10,

to Mr. W. T. Taylor, for his paper, "Modern Long-distance Transmission of Electrical Energy."

AN EXTRA PREMIUM, value £5,

to Dr. E. Rosenberg, for his paper, "Control of Electric Winding and Hoisting Engines."

A PREMIUM, value £5,

to Mr. C. C. Hawkins, for his paper, "The Theory of the Static Balancer."

STUDENTS' PREMIUMS.

A STUDENTS' PREMIUM, value £10,

to Messrs. G. W. P. Page and G. J. Scott, for their paper, "Single-phase Commutator Motors, especially the Latour-Winter-Eichberg Type."

A STUDENTS' PREMIUM, value £5,

to Mr. Hugh C. May, for his paper, "Notes on the Design and Construction of Dry-core Lead-covered Telephone Cables."

A STUDENTS' PREMIUM, value £5,

to Mr. Allan Monkhouse, for his paper, "Recent Electric Locomotive Practice and the High-tension Direct-current Railway System."

A STUDENTS' PREMIUM, value £5,

to Messrs. R. C. Plowman and E. F. Hetherington, for their paper, "Exhaust Steam Turbines."

A STUDENTS' PREMIUM, value £5,

to Mr. A. R. Stelling, for his paper, "Organisation and the Reduction of Manufacturing Costs."

SCOTTISH LOCAL SECTION.

At the end of last March the Council granted a request from members residing in Scotland that the name of the Glasgow Local Section should be changed to Scottish Local Section, and that it should include all members residing in Scotland.

STUDENTS' SECTIONS.

At the opening meeting of the Session an address to the students was delivered by Mr. C. H. Wordingham.

Ten meetings of the Students' Section have been held, at which papers were read and discussed.

The Committee of the Students' Section organised a visit to Birmingham in 1910, when the following works and places of interest were visited: The British Thomson-Houston Company, Rugby; Messrs. Bellis and Morcom; Messrs. Humber (Coventry); the Electric Construction Company and Corporation Tramways, Wolverhampton; Messrs. Alfred Hickman, Bilston; the Birmingham University; Messrs. Siemens Bros. Dynamo Works, Stafford; the General Electric Company; the Birmingham Corporation Generating Station; and the Sandwell Park Colliery, to all of whom the cordial thanks of the Institution are due.

The Annual Dinner of the Students' Section, held on February 18, 1911, was well attended.

The Glasgow and Manchester Students' Sections have each completed a successful session, having held six and nine meetings respectively. Visits were made to various works by the kind permission of the firms concerned.

THE INSTITUTION BUILDING.

During the last week of June, 1910, the offices were transferred to the Institution Building from 92, Victoria Street, Westminster, S.W. The structural alterations were completed and the Lecture Theatre, the Common Room, and the Library were ready for use on the occasion of the delivery of the Inaugural Address of the President, on November 10, 1910.

The Council believe that the influence of the Institution on the interests of the electrical industry can be greatly extended by the practice of gathering together various kindred Institutions and Asso-

ciations. With this in view the Council have granted the use of the Lecture Theatre and of meeting-rooms to a number of engineering bodies, among others the Institution of Post Office Electrical Engineers, the Municipal Electrical Association, the Faraday Society, the Rontgen Society, the National Electrical Manufacturers' Association, the National Electrical Contractors' Association, the Associated Municipal Engineers of Greater London, the Junior Institution of Engineers, and the Society of Engineers. The use of the Lecture Theatre has also been granted to the University of London for the delivery of a course of lectures on "The Application of Hyperbolic Functions to Electrical Engineering Problems," by Dr. A. E. Kennelly, of Harvard University, from the 29th of May to the 2nd of June, 1911.

The Council desire to draw the attention of members to the Common Room which is available for use as a reading and smoking room, and for appointments and interviews. It is also generally possible for members to obtain the use of one of the committee rooms, especially in the morning, by applying to the Secretary a few days in advance.

THE BRITISH ELECTROTECHNICAL COMMITTEE.

The British Committee for 1911 is constituted as follows :—

Mr. A. Siemens (President).	Mr. W. M. Mordey.
Col. R. E. Crompton, C.B.	Mr. H. W. Miller.
Mr. W. Duddell, F.R.S.	Major W. A. J. O'Meara, C.M.G.
Mr. K. Edgcumbe.	Mr. W. H. Patchell.
Mr. S. Z. de Ferranti.	Sir W. H. Preece, K.C.B., F.R.S.
Sir John Gavey, C.B.	Lord Rayleigh, O.M., F.R.S.
Dr. R. T. Glazebrook, C.B., F.R.S.	Dr. A. Russell.
Mr. R. Kaye Gray.	Mr. J. F. C. Snell.
Mr. R. Hammond.	Dr. S. P. Thompson, F.R.S.
Mr. R. W. Hammond.	Mr. A. P. Trotter.
Mr. C. Le Maistre.	Mr. E. B. Vignoles.
Prof. T. Mather, F.R.S.	Mr. C. H. Wordingham.

Mr. P. F. Rowell (*Secretary*).

During the last Session progress has been made with the preparation of the List of Electrotechnica Terms. The Nomenclature Sub-Committee have under consideration the German List of Terms submitted at the Brussels Conference, and definitions are being prepared for the terms not already in the English List.

On the 8th, 9th, and 10th of August, 1910, an unofficial Conference, arranged by the Belgian Electrotechnical Committee and presided over by Professor Eric Gerard, Director of the Institut Electrotechnique Montefiore at Liége, was held in Brussels in the Council Chamber of the Ministry of the Belgian State Railways. The British Committee were represented by Mr. Alexander Siemens (President of the Com-

mittee), Mr. W. Duddell, F.R.S., Mr. K. Edgcumbe, Mr. Robert Hammond, Major W. A. J. O'Meara, C.M.G., Mr. W. H. Patchell, and Mr. P. F. Rowell (Secretary).

The Conference discussed a number of propositions in reference to nomenclature, symbols, the direction of rotation for vectors, and the rating of electrical machines; and eventually passed certain informal resolutions embodying suggestions on these subjects with a view to their being considered by the various Committees and, if approved, ratified at the next meeting of the International Electrotechnical Commission which will be held in Turin in September, 1911.

At the conclusion of the sittings the members of the Conference were entertained by the Belgian Committee to a number of functions and visits to places of engineering interest at Charleroi, Liége, and Antwerp.

"Science Abstracts."

The volumes for 1910 were of nearly the same size as those for 1909, the number of abstracts and references being 1810 in the Physics Section and 1104 in the Electrical Engineering Section.

Wiring Rules.

The revised edition (the sixth) of the Wiring Rules, which was published on the 1st of May, has been prepared to meet as far as possible the developments of the electrical industry. In preparing this edition the Council have had the assistance of some of the principal Fire Offices, the Incorporated Municipal Electrical Association, the Electrical Contractors' Association, and the Cable Makers' Association, all of whom were represented on the Committee who carried out the work of revision on behalf of the Council.

The figures in the table relating to the current-carrying capacities of conductors are based on an exhaustive series of tests carried out at the National Physical Laboratory on the temperature-rise of conductors.

The new Rules have been adopted by 49 Fire Offices, and they are accepted as standard practice and their use recommended by 232 Supply Authorities.

Model General Conditions for Contracts.

A draft revision of the Model General Conditions for Contracts has been completed, and the clauses are at present under further consideration with a view to their being made acceptable to a larger number of interested bodies.

Electricity in Textile Mills.

The Committee appointed to consider this subject have had several meetings.

Street Lighting Specification.

The Council have appointed a committee consisting of representatives of this Institution, and of representatives nominated by the Councils of the Institution of Gas Engineers, the Institution of Municipal and County Engineers, and the Illuminating Engineering Society, to consider the preparation of a specification for street lighting to be issued jointly under the auspices of the various interested bodies.

Kelvin Lecture.

The third Kelvin Lecture will be delivered next autumn by Dr. R. T. Glazebrook, C.B., F.R.S. The subject will be Lord Kelvin's work in connection with fundamental units, and to a considerable extent the lecture will be experimental.

Examinations for Associate Members.

The Council have decided to hold examinations of candidates for election and transfer to the class of Associate Members after 1st January, 1913. Candidates will be required to pass—

(*a*) An examination in general knowledge, and
(*b*) An examination in one of the four special subjects :—

1. Power, Lighting, and Traction.
2. Telegraphy.
3. Telephony.
4. Electrochemistry and Electrometallurgy.

The questions will be set with the object of showing that the candidates possess a good general education and a reasonable amount of fundamental knowledge in one of the branches of the profession. Due consideration will also be given to the practical side of electrical engineering, and moreover the candidate's admission or rejection will not depend solely on his answers to the papers set, but these will be considered in conjunction with the candidate's practical experience, which must be in accordance with the requirements of the Articles of Association.

In lieu of examination, candidates will be allowed to present a thesis, paper, or other contribution to electrical knowledge, and they will be liable to be examined orally by the examiners on the subject presented. Certain Degrees or Diplomas will procure exemption from the whole or part of the examination, and the Council will have power in approved cases to grant exemptions.

The complete details are under consideration with a view to publication at an early date.

Examinations for Students.

The Council have decided that from 1st January, 1913, candidates for election as Students shall be required to pass or to have passed either the Matriculation Examination of one of the British Universities or some school-leaving or other equivalent examination which shall satisfy the Council of the candidates' general education. In view of the number of existing examinations, which is already very large, the Council deemed it wise not to conduct a special examination.

Full details will be available at an early date.

Journal.

It has been felt for some time that it would be desirable to make arrangements for a more frequent publication of the *Journal*, so as to ensure that members shall receive promptly full and accurate reports of the papers read and of the discussions at the meetings of the Institution and of the Local Sections, and the Council have accordingly given instructions for a report to be prepared on the subject. The value of the lectures and of the papers and discussions at the informal meetings mentioned elsewhere in this Report would be greatly increased by early distribution among the members as a whole, and especially those residing abroad or at a distance from the place of meeting. It is also hoped that the result would be to render the *Journal* more efficient as a means of communication between the Council and the members. The advantages of publication at shorter intervals than six weeks (as under the present system) are so obvious as not to require mention in detail, but in view of the gross expenditure on the *Journal*, which at present stands at £2,080 per annum, exclusive of salaries and cost of office accommodation, and would necessarily be increased by such a change, at least during the first few years, the decision of the Council in regard to this matter will largely be governed by the funds at the disposal of the Institution.

Lectures.

The Council have under consideration the subject of lectures at meetings of the Institution and of the Local Sections. The lectures would be on electrical subjects or on subjects scientific, economic financial, or commercial, connected with electrical science or engineering, treated in a general manner, and if possible illustrated by experiments. The underlying idea of the lectures is to bring before the members general surveys treated by authorities who have specialised in their own subjects, the object being to keep the members in touch with those outlying branches of electrical science and engineering which are not usually considered in the papers read before the Institution, and also to keep members informed of the progress of allied sciences of interest to electrical engineers. The lectures, the matter for which would not necessarily be new, would be published in the *Journal* in short abstract only, and it is not intended that there should

be any discussion on them. It is proposed to hold two lectures each session, either on the evenings reserved for Ordinary Meetings or some other evening.

Informal Meetings.

There are many subjects of considerable interest to a limited number of the members, which for various reasons are not of sufficient importance or of sufficiently general interest for the Ordinary Meetings of the Institution, and the Council have accordingly under consideration arrangements for Informal Meetings for reading papers and discussing matters relating to such subjects. The papers would be short, so as to leave ample time for discussion. To begin with, it is suggested that four meetings a session be held, which could be increased later if required. A short abstract of the papers would be published in the *Journal*, together with an abstract of the discussions.

Summer Meetings.

It is proposed to consider whether arrangements can be made for holding meetings of the Institution in the districts of the different Local Sections. Each meeting would last for three or four days, part of the time being given to the reading and discussion of papers and part to visiting the industries of the particular district.

Subscriptions and Entrance Fees.

The Council feel that the time has now arrived when the development of the Institution, as well as the maintenance of its prestige among the great engineering institutions of the world and the possibilities in the direction of increasing its usefulness to the profession, make it imperative that the members should contribute higher annual subscriptions and entrance fees. These are at present less than those paid to other professional Institutions of equal standing. This matter has recently been under the consideration of the Council, and at the next revision of the Articles of Association proposals on this subject will be placed before the members.

Articles of Association.

The Committee appointed to consider the alterations required in the Articles of Association will shortly present their report to the Council.

Benevolent Fund.

The Committee of Management report that the Benevolent Fund of the Institution shows a satisfactory increase for the past year. On 31st December, 1910, the capital account of the Fund stood at £3,700, as compared with £3,500 at the end of 1909. The accounts will be found on page 854. The donations to the Fund in 1910 include one of £20 from the Committee of the Electrical Engineers' Ball, and one of £8 8s. from the "25" Club. The Council desire to acknowledge their indebtedness to the generosity these and other donors

and subscribers who have supported the Fund. Grants in aid amounting to £51 were made during 1910.

The Wilde Benevolent Trust Fund stands at £1,846 4s. 6d.

Annual Accounts.

The Report of the Hon. Treasurer, Mr. Robert Hammond, is as follows:—

Income and Expenditure.—The balance carried to the General Fund at the end of 1910, being excess of income over expenditure, was £3,053 0s. 2d., as compared with £3,283 3s. 11d. for 1909, a decrease of £230 3s. 9d. In this comparison no account is taken of outlays in connection with the acquisition and structural alteration of the Institution Building.

Balance Sheet.—The balance sheet sets out the total investments other than the investments of the Trust Funds. It will be seen that the total assets amount to £102,686 17s. 6d., against which are to be set liabilities amounting to £42,851 15s. 10d., leaving as the net assets of the Institution £59,835 1s. 8d. This amount is almost entirely locked up in the acquisition of the lease of the Institution Building, in the structural alterations, and in the expenses incurred prior to occupation.

The investments in stocks and shares included in the above appear in the accounts at cost price with a book value of—

	£	s.	d.
General Fund	2,270	12	0
Kelvin Lecture Fund...	862	10	10
	£3,133	2	10

and their value at the current market prices on 27th April, 1911, was £2,864.

Trust Funds.—No alteration has taken place during the year under consideration in the two Scholarship Trust Funds. The Wilde Benevolent Trust Fund has been increased by the investment of an amount of £101 8s. 6d. transferred from Income Account, and it now stands at £1,846 4s. 6d.

Life Compositions.—This Fund has been increased during the year by £30 9s., and stands at £5,642 12s., which amount now figures in the accounts as a loan to the Building Fund, the investments of the Fund having all been realised.

Entrance Fees Fund.—An increase is shown of £816 6s. This amount has been transferred to the Building Fund.

Building Fund.—In consequence of the acquisition of the Lease of the Institution Building, the Fund has been augmented as follows: (*a*) permanently, by transfer of £816 6s. from the Entrance Fees Fund, and by revenue from subscriptions, donations, and sundry other items, £109 11s. 6d.; (*b*) temporarily by loans, on mortgage from the Economic Life Assurance Society £11,500, from Life Compositions Fund £30 9s., and from General Fund £4,047 15s. 11d., against which

£599 17s. 11d. has been repaid to the Economic Society on account of existing loans. This makes a net increase of £15,904 4s. 6d., and the Fund now stands as follows :—

	£	s.	d.
Cost of the Lease of the Institution Building, including Structural Alterations and Expenses during the same, Mortgage Expenses, Loss on Sale of Securities	73,028	6	10
Tothill Street Property	19,260	17	1
	£92,289	3	11

General Fund.—This Fund has increased to the extent of £3,053 0s. 2d. during the past year, and now stands at £13,188 10s. 10d.

Summary.—The increases of the Funds during the year have been as follows :—

	£	s.	d.
Entrance Fees...	816	6	0
Building Fund	109	7	6
General Fund	3,053	0	2
	£3,978	13	8

LIBRARY.

The Council wish to draw the attention of the members to the present arrangement of the Library. The whole of the books published since 1890 have been classified, and a subject index is being prepared. The eastern half of the shelves under the gallery contain the classified portion of the books, the bound volumes of the principal periodicals being on the western half of the shelves. The books of the Ronalds Library are on the central shelves above the gallery.

Seventy-six new books have been purchased since May 1910, and 181 books and pamphlets have been presented by members, authors, and publishers. The total number of readers during the past twelve months was 1,024, of whom 82 were non-members. The Council have under consideration the formation of a Lending Library and the opening of the Library in the evenings.

MUSEUM.

Some of the historical apparatus which has been presented to the Institution is temporarily on view in the glass cases in the Library, and a room in the basement has been set apart for the exhibition of other electrical apparatus in the possession of the Institution. The apparatus is in process of being sorted and classified.

APPENDIX TO REPORT.

TRANSACTIONS, PROCEEDINGS, ETC., RECEIVED BY THE INSTITUTION.

BRITISH.

British Association for the Advancement of Science, Reports.
Cambridge Philosophical Society, Proceedings.
Chartered Institute of Patent Agents, Transactions.
Faraday Society, Transactions.
Greenwich Magnetical and Meteorological Observations.
Incorporated Institution of Automobile Engineers, Proceedings.
Illuminating Engineering Society, Transactions.
Incorporated Municipal Electrical Association, Proceedings.
Institute of Chemistry, Proceedings.
Institute of Marine Engineers, Transactions.
Institute of Metals, Journal.
Institution of Civil Engineers, Proceedings.
Institution of Engineers and Shipbuilders in Scotland, Transactions.
Institution of Mechanical Engineers, Proceedings.
Institution of Mining and Metallurgy, Transactions and Bulletin.
Institution of Naval Architects, Transactions.
Institution of Post Office Electrical Engineers, Papers.
Iron and Steel Institute, Journal and Carnegie Memoirs.
Liverpool Corporation Tramways, Annual Reports.
Liverpool Engineering Society, Proceedings.
Manchester Literary and Philosophical Society, Memoirs and Proceedings.
Municipal School of Technology, Manchester Journal.
National Physical Laboratory Reports, and Collected Researches.
North-East Coast Institution of Engineers and Shipbuilders, Transactions.
North of England Institute of Mining and Mechanical Engineers, Transactions.
Physical Society, Proceedings.
Röntgen Society, Journal.
Royal Dublin Society, Scientific and Economic Proceedings.
Royal Institution, Proceedings.
Royal Meteorological Society, Quarterly Journal and Monthly Notes.
Royal Society, Philosophical Transactions and Proceedings.
Royal Society of Arts, Journal.
Royal Society of Edinburgh, Transactions and Proceedings.
Royal United Service Institution, Journal.

Society of Chemical Industry, Journal.
Society of Engineers, Transactions.
Surveyors' Institution, Transactions and Professional Notes.
Tramways and Light Railways' Association, Journal.

COLONIAL.

Canadian Electrical Association, Proceedings.
Canadian Society of Civil Engineers, Transactions.
Engineering Association of New South Wales, Proceedings.
Engineering Society of Toronto, Transactions.
Indian Telegraph Department, Administration Reports.
Nova Scotia Institute of Science, Transactions and Proceedings.
Royal Society of Queensland, Proceedings.
Royal Society of Victoria, Proceedings.
South Australia, Meteorological Observation Reports.
Sydney University of Engineering, Proceedings.

AMERICAN.

American Academy of Arts and Sciences, Proceedings.
American Electrochemical Society, Transactions.
American Institute of Electrical Engineers, Transactions and Proceedings.
American Institute of Mining Engineers, Transactions and Bi-Monthly Bulletin.
American Philosophical Society, Proceedings.
American Society of Civil Engineers, Proceedings.
American Society of Mechanical Engineers, Transactions and Journal.
Bureau of Standards, Washington, Bulletin.
Engineers' Club of Philadelphia, Proceedings.
Franklin Institute, Journal.
Illuminating Engineering Society, N. Y., Transactions.
National Electric Light Association, Transactions.
Ordnance Department of the United States, Notes.
Smithsonian Institution, Reports.
U.S. Official Patent Gazette.
U.S. Ordnance Report.
Western Society of Engineers, Journal.

AUSTRIAN.

Kaiserliche Akademie der Wissenschaften, Wien, Sitzungsberichte.

BELGIAN.

Association des Ingénieurs Électriciens sortis de l'Institut Électrotechnique Montefiore, Bulletin.

DUTCH.

Koninklijk Institut van Ingenieurs, Tijdschrift.
Koninklijke Akademie van Wetenschappen, Amsterdam, Proceedings.

FRENCH.

Académie des Sciences, Comptes Rendus Hebdomadaires des Séances.
Bureau des Longitudes, Annuaire.
Société des Anciens Élèves des Ecoles Nationales d'Arts et Metiers Bulletin Technologique.
Société des Ingénieurs Civils, Mémoires.
Société Française de Physique, Bulletin des Séances.
Société Internationale des Électriciens, Bulletin.
Société Scientifique Industrielle de Marseille, Bulletin.

GERMAN.

Physikalische Technische Reichsanstalt, Abhandlungen.
Schiffbautechnische Gesellschaft, Jahrbuch.
Verein Deutscher Ingenieure, Zeitschrift.
Verein zur Beförderung des Gewerbfleisses, Verhandlungen.

ITALIAN.

Associazione Elettrotecnica Italiana, Atti.
Reale Accademia dei Lincei, Atti e Memorie.

JAPANESE.

College of Science, Kyoto, Memoirs.

SWEDISH.

K. Svenska Vetenskaps-Akademien, Arkiv för Matematik, etc.

SWISS.

Association Suisse des Électriciens, Annuaire, et Bulletin.

LIST OF PERIODICALS RECEIVED BY THE INSTITUTION.

BRITISH.

Aero.
Automobile Owner.
Cassier's Magazine.
Central.
Colliery Guardian.
Electrical Engineer.
Electrical Engineering.
Electrical Field.
Electrical Industries.
Electrical Review.
Electrical Times.
Electrician.
Electricity.
Engineer.
Engineering.
Engineering Magazine.
Engineering Review.
English Mechanic.
Illuminating Engineer.
Illustrated Official Journal, Patents.
Iron and Coal Trades Review.
Light Railway and Tramway Journal.
Mechanical Engineer.
Mining Journal.
National Telephone Journal.
Nature.
Page's Weekly.
Philosophical Magazine.
Post Office Electrical Engineers' Journal.
Railway News.
Railway Times.
Royal Engineers' Journal.
Scientific Monthly.
Surveying and Civil Engineer.
Tramway and Railway World.
Vulcan.

COLONIAL.

Australian Mining Standard.
Australian Official Journal of Patents.
Canadian Machinery.
Electrical News (Toronto).
Indian Industries and Power.

AMERICAN.

American Journal of Science.
Electric Journal.
Electric Railway Journal.
Electrical Review and Western Electrician.
Electrical World.
Engineering News.
India Rubber World.
Journal of the Telegraph.
Metallurgical and Chemical Engineering.
Physical Review.
Scientific American.
Telephony.
Terrestrial Magnetism and Atmospherical Electricity.

AUSTRIAN.

Elektrotechnik und Maschinenbau.

BELGIAN.

Revue de l'Electricité.

DANISH.

Teknisk Tidsskrift.

DUTCH.

De Ingenieur.

FRENCH.

Annales des Postes, Télégraphes, et des Téléphones.
Archives des Sciences Physiques et Naturelles.
Electricien.
Houille Blanche.
Industrie Électrique.
Journal de Physique.
Journal Télégraphique.
Lumière Électrique.
Mois Scientifique et Industriel.
Portefeuille Economique des Machines.
Revue Électrique.

GERMAN.

Annalen der Elektrotechnik.
Annalen der Physik.
Annalen der Physik, Beiblätter.
Elektrische Kraftbetriebe und Bahnen.
Elektrotechnische und Polytechnische Rundschau.
Elektrotechnische Zeitschrift.
Elektrotechnischer Anzeiger.
Fortschritte der Elektrotechnik.
Glückauf.
Jahrbuch der drahtlosen Telegraphie.
Jahrbuch der Elektrochemie.
Jahrbuch der Radioaktivität.
Physikalische Zeitschrift.
Zeitschrift für Elektrochemie.
Zeitschrift für Instrumentenkunde.
Zeitschrift für Schwachstromtechnik.

ITALIAN.

L'Elettricista.
L'Elettricita.
Giornale del Genio Civile.
Il Nuovo Cimento.

SPANISH.

La Ingenieria.

SWISS.

Schweizer ische Elektrotechnische Zeitschrift.

The Institution of

STATEMENT OF EXPENDITURE AND
ENDED 31st

Dr. EXPENDITURE.

To MANAGEMENT :—				£	s.	d.	£	s.	d.
Salaries and Wages				2,075	7	0			
Accountants' Fees				21	0	0			
Printing and Stationery				570	16	0			
Addressing (Notices)				62	0	1			
Postage (Correspondence and Notices) ...				375	18	9			
Telephone				26	17	3			
Travelling Expenses				39	17	3			
Bank Charges				6	5	7			
							3,178	1	11
„ RENT, INSURANCE, LIGHTING, AND FIRING (at 92, Victoria Street)							307	14	4
„ INSTITUTION BUILDING (1st July to 31st December, 1910) :—									
Ground Rent				1,100	10	0			
Rates and Taxes				645	18	7			
Lighting and Firing				64	12	11			
Insurance				20	15	2			
Repairs				32	17	0			
Household Requisites and Cleaning... ...				106	1	9			
							1,970	15	5
„ INTEREST ON MORTGAGES (1st July to 31st December, 1910) :—									
Institution Building				539	15	1			
Tothill Street Property				224	0	3			
							763	15	4
„ SINKING FUND PREMIUMS							277	12	2
„ REMOVAL AND RENOVATION OF FURNITURE ...							149	11	2
„ JOURNAL :—									
Printing				1,499	12	3			
Postage				515	8	6			
Addressing				16	19	8			
Advertising				47	5	8			
				2,079	6	1			
Less Receipts—									
Sales	£278	12	11						
Advertisements	392	0	0						
				670	12	11			
							1,408	13	2
„ "SCIENCE ABSTRACTS"—									
Salaries, Abstracting, Printing, Postage, etc.				1,552	8	11			
Less Subscriptions, Sales, and Advertisements				1,217	14	5			
							334	14	6
Carried Forward							£8,390	18	0

Electrical Engineers.

INCOME FOR THE YEAR DECEMBER, 1910.

INCOME. Cr.

		£	s.	d.
By Subscriptions		11,314	19	6
„ Dividends on Investments		79	16	10
„ Interest		55	19	3
„ Model General Conditions—Sales		4	12	7
„ Institution Building (1st July to 31st December, 1910) :—				
Rent from Tenants		1,487	10	0
„ Tothill Street Property :—				
Rent from Tenants	£590 7 6			
Less Ground Rent, Rates, Taxes, &c. ...	322 19 3			
		267	8	3
Carried Forward		£13,210	6	5

STATEMENT OF EXPENDITURE AND
ENDED 31st

Dr. EXPENDITURE—*continued.*

	£	s.	d.	£	s.	d.
Brought Forward				8,390	18	0
To MEETINGS :—						
Advance Proofs, Refreshments, etc.	157	17	1			
Reporting	49	18	6			
				207	15	7
„ LOCAL SECTIONS :—						
Grants	640	17	11			
Travelling Expenses	88	18	0			
				729	15	11
„ PREMIUMS				126	7	7
„ BRITISH ELECTROTECHNICAL COMMITTEE				88	1	2
„ CONVERSAZIONE				241	19	10
„ DEPRECIATION :—						
Library	165	19	11			
Furniture	93	9	6			
				259	9	5
„ WIRING RULES :—						
Materials for Tests	21	14	6			
Less Sales	9	11	7			
				12	2	11
„ LEGAL EXPENSES				16	18	9
„ MISCELLANEOUS EXPENSES				83	17	1
„ BALANCE carried to General Fund				3,053	0	2
				£13,210	6	5

INCOME FOR THE YEAR DECEMBER, 1910—(*continued*).

INCOME—*continued*. **Cr.**

	£	s.	d.
Brought Forward	13,210	6	5
	£13,210	6	5

BALANCE SHEET,

Dr.

LIABILITIES.

	£ s. d.	£ s. d.
To Salomons Scholarship Trust Fund		38 16 4
„ David Hughes Scholarship Trust Fund :—		
Capital uninvested	1 5 0	
Income	22 14 6	
		23 19 6
„ Wilde Benevolent Trust Fund		122 9 5
„ Life Compositions Fund		5,643 12 0
„ Building Fund		40,115 8 0
„ Kelvin Lecture Fund :—		
Capital	862 10 10	
Income	25 0 0	
		887 10 10
„ Sundry Creditors		5,565 0 8
„ Economic Life Assurance Society		36,900 2 1
„ Local Sections :—		
Due to Hon. Sec. Birmingham Local Section	35 1 11	
Due to Hon. Sec. Dublin Local Section ...	8 1 7	
Due to Hon. Sec. Newcastle Local Section	12 0 4	
		55 3 10
„ Subscriptions received in advance		106 14 0
„ Foreign Visit Fund		39 10 0
„ General Fund		13,188 10 10
		£102,686 17 6

ROBERT HAMMOND
Honorary Treasurer.

P. F. ROWELL,
Secretary.

We beg to report that we have audited the Balance Sheet of the Institu-
together with the annexed Statements of Account. We have obtained all the
ments are correct, and the Balance Sheet is properly drawn up so as to
according to the best of our information and the explanations given to

ALLEN, BIGGS & CO.,
Chartered Accountants,
147 Leadenhall Street, E.C.

27th April, 1911.

31st DECEMBER, 1910.

Cr.

ASSETS.

		£	s.	d.	£	s.	d.
By General Fund Investments	(at cost)				2,270	12	0
„ Kelvin Lecture Fund Investments	„				862	10	10
„ Tothill Street Buildings and Site	„				19,260	17	1
„ Institution Building and Lease* ...	„				73,028	6	10
„ Sundry Debtors					969	10	6
„ Local Sections :—							
Cash in hands of Hon. Sec. Glasgow Local Section...		20	4	1			
Cash in hands of Hon. Sec. Manchester Local Section...		18	2	0			
Cash in hands of Hon. Sec. Yorkshire Local Section...		8	1	6			
					46	7	7
„ Library					1,493	19	6
„ Vellum Diploma Forms					1	3	9
„ Furniture and Fittings					1,776	1	2
„ Unexpired Balances of Fire Insurance Premiums		82	9	3			
„ Rates Paid in Advance		229	16	4			
					312	5	7
„ Cash :—At Bankers'		2,485	12	6			
Petty Cash		57	0	9			
P.O. Savings Bank (Wilde Benevolent Trust Fund)		122	9	5			
					2,665	2	8
					£102,686	17	6

* Policies payable on the 24th of June, 1984, have been taken out with the Alliance Assurance Co. for £25,000, and the Economic Life Assurance Co. for £50,000, as provision for amortisation of expenditure on the Institution Building and Lease. The total amount of premiums paid to date is £460 18s. 10d., the surrender value of which at date is £183 6s. 8d.

tion of Electrical Engineers, dated 31st December, 1910, and above set forth, information and explanations we have required. In our opinion the State-exhibit a true and correct view of the state of the Institution's affairs us and as shown by the books of the Institution.

H. ALABASTER
SIDNEY SHARP } *Honorary Auditors.*

Dr.

	£	s.	d.	£	s.	d.
To Excesses of Income over Expenditure to 31st December, 1909				36,635	12	10
Add Excess of Income over Expenditure for 1910				3,053	0	2
				39,688	13	0
Less Transfers (as per last Account) :—						
To Building Fund	25,637	11	4			
To Kelvin Lecture Fund	862	10	10			
				26,500	2	2
				£13,188	10	10

FUND.

Cr.

	£	s.	d.	£	s.	d.	£	s.	d.
By Investment (at cost) :—									
£2,600 Natal Zululand Railways 3% Debentures							2,270	12	0
" Balance made up as follows :—									
ASSETS.									
Sundry Debtors	969	10	6						
Cash in Hand	2,711	10	3						
Furniture	1,776	1	2						
Library	1,493	19	6						
Rates and Insurance Premiums in Advance ...	312	5	7						
Vellum Diploma Forms ...	1	3	9						
Due from Building Fund...	9,630	1	10						
				16,894	12	7			
LIABILITIES.									
Uninvested Balances of Special Funds	249	15	3						
Sundry Creditors	5,620	4	6						
Subscriptions in Advance	106	14	0						
				5,976	13	9			
							10,917	18	10
							£13,188	10	10

BUILDING

Dr.

	£	s.	d.	£	s.	d.
To Amount (as per last Account)				39,189	10	6
" " transferred from Entrance Fees Fund				816	6	0
" Subscriptions and Donations				104	7	6
" Surplus from Vellum Diplomas				5	4	0
				40,115	8	0
" Balance made up as follows :—						
Due to Life Compositions Fund	5,643	12	0			
Due to General Fund	9,630	1	10			
Due to the Economic Life Assurance Society :—						
On mortgage of :—						
Institution Building ... 26,000 0 0						
Less Repaid 599 17 11						
	25,400	2	1			
Tothill Street Buildings and Site ...	11,500	0	0			
				52,173	15	11
				£92,289	3	11

ENTRANCE FEES

Dr.

	£	s.	d.
To Entrance Fees from 1902 to 1909— (As per last Account)	5,921	1	6
" Entrance Fees received in 1910	816	6	0
	£6,737	7	6

FUND.

Cr.

	£	s.	d.	£	s.	d.	£	s.	d.
By Tothill Street Buildings and Site (as per last Account)...							19,260	17	1
„ Institution Building and Lease :—									
(*a*) Outlays thereon :—									
Purchase Money	50,000	0	0						
„ Expenses ...	544	19	0						
Structural Alterations to 31st December, 1910 ...	18,380	19	8						
				68,925	18	8			
(*b*) Expenses prior to occupation (1st June, 1909, to 30th June, 1910) :—									
Ground Rent	2,340	1	6						
Rates and Taxes	1,003	17	1						
Repairs	78	4	4						
Insurance	29	7	9						
Mortgage Interest	1,191	0	8						
	4,642	11	4						
Less Rent from Tenants (1st June, 1909, to 30th June, 1910)	3,273	19	10						
				1,368	11	6			
(*c*) Mortgage Expenses				651	15	6			
(*d*) Loss on Sale of Securities				2,082	1	2			
							73,028	6	10
							£92,289	3	11

FUND.

Cr.

	£	s.	d.
By Building Fund :—			
Amounts transferred (as per last Account)	5,921	1	6
Amount transferred in 1910	816	6	0
	£6,737	7	6

LIFE COMPOSITIONS

Dr.

	£	s.	d.
To Amount (as per last Account)	5,613	3	0
„ Life Composition received in 1910	30	9	0
	£5,643	12	0

KELVIN LECTURE

Dr.

	£	s.	d.	£	s.	d.
To Amount (as per last Account)				887	10	10
„ Dividends	25	0	0			
Less Lecturer's Honorarium	25	0	0			
				£887	10	10

LIBRARY.

Dr.

	£	s.	d.
To Amount (as per Balance Sheet)	1,493	19	6
	£1,493	19	6

FUND.

Cr.

	£	s.	d.
By Balance (due from Building Fund)	5,643	12	0
	£5,643	12	0

FUND.

Cr.

	£	s.	d.
By Investment (at cost) :—			
£1,000 2½% Consolidated Stock	862	10	10
„ Balance Uninvested	25	0	0
	£887	10	10

LIBRARY.

Cr.

	£	s.	d.
By Outlays on Books, Pictures, etc., to 31st December, 1909 ...	2,508	9	7
Less Provision for Depreciation (1901–9)	988	5	6
As per last Balance Sheet	1,520	4	1
„ Expenditure on Books and Binding in 1910	139	15	4
	1,659	19	5
Less 10% Depreciation for 1910	165	19	11
	£1,493	19	6

SALOMONS SCHOLARSHIP

Dr.

	£	s.	d.
To Amount (as per last Account)	2,126	19	3
	£2,126	19	3

SALOMONS SCHOLARSHIP

Dr.

	£	s.	d.
To Amount paid to Scholars in 1910...	50	0	0
„ Balance carried to Balance Sheet	38	16	4
	£88	16	4

DAVID HUGHES SCHOLARSHIP

Dr.

	£	s.	d.
To Amount (as per last Account)	2,000	0	0
	£2,000	0	0

DAVID HUGHES SCHOLARSHIP

Dr.

	£	s.	d.
To Amount paid to Scholars in 1910...	75	0	0
„ Balance carried to Balance Sheet	22	14	6
	£97	14	6

WILDE BENEVOLENT

Dr.

	£	s.	d.
To Amount (as per last Account)	1,744	16	0
„ transferred from Income	101	8	6
	£1,846	4	6

WILDE BENEVOLENT

Dr.

	£	s.	d.
To Amount transferred to Capital Account	101	8	6
„ Balance carried to Balance Sheet	122	9	5
	£223	17	11

TRUST FUND.

	£	s.	d.
		Cr.	
By Investments (at cost) :—			
£1,500 New South Wales 3½ % Stock	1,556	5	9
£500 Cape of Good Hope 3½ % Stock	570	13	6
	£2,126	19	3

TRUST FUND (Income).

	£	s.	d.
		Cr.	
By Balance (as per last Account)	18	16	4
„ Dividends received in 1910	70	0	0
	£88	16	4

TRUST FUND.

	£	s.	d.
		Cr.	
By Investment (at cost) :—£2,045 Staines Reservoirs 3 % Guaranteed Debenture Stock	1,998	15	0
„ Balance carried to Balance Sheet	1	5	0
	£2,000	0	0

TRUST FUND (Income).

	£	s.	d.
		Cr.	
By Balance (as per last Account)	36	7	6
„ Dividends received in 1910	61	7	0
	£97	14	6

TRUST FUND.

	£	s.	d.
		Cr.	
By Investments (at cost):—			
£875 Great Eastern Railway Metropolitan 5 % Guaranteed Stock	1,493	16	3
£215 North Eastern Railway 4 % Guaranteed Stock ...	250	19	9
£100 London County 3½ % Stock	101	8	6
	£1,846	4	6

TRUST FUND (Income).

	£	s.	d.
		Cr.	
By Balance (as per last Account)	165	11	8
„ Dividends received in 1910	55	17	0
„ Interest do. do.	2	9	3
	£223	17	11

THE BENEVO-

The Institution of

Statement of Accounts

Dr. CAPITAL

	£	s.	d.
To Balance as per last Account	3,500	0	0
„ Transfer from Income	200	0	0
	£3,700	0	0

Dr. INCOME AND

	£	s.	d.
To Balance as per last Account	203	15	11
„ Dividends on Investments...	117	13	8
„ Interest on Deposit	2	17	1
„ Donations under £5	5	10	2
„ Donations of £5 and over	43	13	0
„ Annual Subscriptions	95	13	8
	£469	3	6

Dr. BALANCE

	£	s.	d.
To Capital	3,700	0	0
„ Income and Expenditure Account	215	6	3
„ Sundry Creditors	1	11	0
	£3,916	17	3

We have examined the above Accounts with the Receipt Book, Cash Book, and we find them to be correct.

March 22, 1911.

LENT FUND OF

Electrical Engineers.

to December 31, 1910.

ACCOUNT. Cr.

	£	s.	d.
By Balance carried to Balance Sheet, viz. :—			
Investments—			
£961 7s. 7d. Cape of Good Hope 3 % Stock	950	0	0
£593 1s. 7d. New South Wales 3% Stock	600	0	0
£420 Great Eastern Railway 4 % Pref. Stock...	503	18	3
£600 North Staffordshire Railway 3 % Deb. Stock	551	0	9
£750 East Indian Railway 3½ % Deb. Stock	737	18	0
£300 London and North Western Railway 4 % Guar. Stock	333	11	6
Cash	23	11	6
	£3,700	0	0

EXPENDITURE ACCOUNT. Cr.

	£	s.	d.
By Grants	51	0	0
„ Postages, Printing, &c.	2	17	3
„ Transfer to Capital	200	0	0
„ Balance carried to Balance Sheet, viz. :—			
Cash	215	6	3
	£469	3	6

SHEET. Cr.

				£	s.	d.
By Investments (Capital Account)—						
£961 7s. 7d. Cape of Good Hope 3 % Stock				950	0	0
£593 1s. 7d. New South Wales 3% Stock				600	0	0
£420 Great Eastern Railway 4 % Pref. Stock				503	18	3
£600 North Staffordshire Railway 3 % Deb. Stock				551	0	9
£750 East Indian Railway 3½ % Deb. Stock				737	18	0
£300 London and North Western Railway 4 % Guar. Stock				333	11	6
				3,676	8	6
„ Cash—						
At Bankers'	£239	12	6			
Petty Cash		16	3			
				240	8	9
				£3,916	17	3

Bankers' Pass Book, and Vouchers, also Bankers' Certificate of Investments,

H. ALABASTER,
SIDNEY SHARP, } *Honorary Auditors.*

The Chairman, having read the Annual Report, called upon Mr. Hammond to present the Financial Statement for the year 1910.

Mr. R. HAMMOND: It is our custom at our Annual Meetings to review our financial position and to compare the operations of the year that has just ended with those of the previous year. As we have been only in this building a matter of six months, as far as the accounts are concerned, it is impossible to make such a comparison as we shall be able to make in future years when comparing like with like and a full year with a full year, but speaking of the accounts as they stand, you will notice on page 842 that there is a balance to the good on the year's operations of £3,053. This includes for the first time, as will be seen from page 841, the amount yielded by the Tothill Street property, £267 8s. 3d. It has been our custom for years to bring the rentals which we have from our Tothill Street property into the Building Fund, but as the Building Fund is practically closed as a Building Fund it was thought wise that in future all our income should appear under the head of Income: therefore in this year's accounts Tothill Street revenue comes in to the extent of £267 8s. 3d. If it were not there, if it were in the same place as last year, our balance to the good would have been reduced by this sum, and would stand at £2,785 11s. 11d. We have it all the same, but if we are going to compare this year's amount to the good with that of last year it is only fair that amount should be deducted. Last year the balance to the good was £3,283 3s. 11d., so that we are not so well off as far as the actual balance is concerned this year by the amount of £497 12s. It is interesting to see how that deficit, if we may so call it for the moment, is arrived at. The item that comes in for rent is slightly in excess to the extent of £65. Then we have interest on mortgage which we had not before. We were receivers of income on our investments, now we are payers of interest on our mortgage. That accounts for an item of £763. Then we have our Sinking Fund which I mentioned at the last Annual Meeting. We thought it wise to set aside a sum which, accumulated at the end of 75 years, will put those gentlemen who live to see it in the position of saying that they have got back all the money spent on the building. That Insurance during the past year was raised from £50,000 to £75,000, and this caused an increased Sinking Fund charge of £94. Then the cost of moving has come in, £149. The *Journal* cost us £34 more last year, and the expenses of the local sections have gone up slightly, to the extent of £150. The Council have always considered it wise in every way to exercise a liberal view of the local sections, and the various papers that have been read and the travelling expenses occasioned have increased the expenditure to the extent of £150. The new building has necessitated a large addition to our furniture, and we cannot have all this furniture in excess of what we had before without putting aside a larger sum for depreciation, £69. The wiring rules are £22 in excess. The item under legal expenses is slightly up. We now show what we were spending on law other than that provided for nothing by our Honorary

Solicitors. Management expenses have increased to the extent of £207. In consequence of the realisation of our investments our income from dividends has fallen off, and the total result is that on the debit side of the budget we are short by £1,752. But on the other side we have items to the good: "*Science Abstracts* cost less during the past year to the extent of £165, and the costs of the meetings show a slight reduction of £5 14s. 8d. Premiums show a saving of 19s. 2d. The British Electrotechnical Committee, which formerly had not a home on our premises, is now here. We felt that one of our first steps on entering possession of our new building was to encourage all kindred societies to come here, and as we were the principal supporters and financially the sole supporters of the British Electrotechnical Committee, it was brought and Mr. Rowell appointed the Secretary, at a saving of £156 during the past year. The Conversazione shows a saving of 14s. 8d. Miscellaneous expenses were less by £57 0s. 3d., and the Annual Dinner was not held last year in consequence of the death of the King, so we shall have the opposite story to tell in next year's accounts, because it will reappear. The total of these items makes £447 towards our deficiency of £1,752. I am glad to be able to report that the subscriptions from members increased to the extent of £756, a point that the Council feel is a subject of great gratification and congratulation in these hard times. That is £756 to be added as well as a slight increase on the interest upon our floating money. We had more money in the bank than we used to have, which gave a credit of £49. All our credits amount to £1,253 against our debit of £1,752, making up a £497 deficiency as compared with the last year, but still leaving us a balance to the good of £3,053 on this account and £109 on the building account for subscriptions that came in during the year, and £816 for entrance fees, making a total to the good of £3,978. Before concluding I would like to draw attention to the balance sheet, which shows that our assets amounted on the 31st December last to £102,686. On the other hand, we had liabilities. There were liabilities to various of our own Funds, such as the General Fund, and so on, but sorting them out from the others our actual liabilities to outsiders, including the mortgages on our property, amounted to £42,851, leaving the net property of the Institution at £59,835. Of course we know we have not that in golden sovereigns: you are looking at a portion of it just now. By the assistance of the money received on mortgage £73,028 was spent on the acquisition of this building. Our Tothill Street property shows a book value of £19,260. It is situated in an improving neighbourhood. Various wealthy people seem to have combined to take such steps as will increase the value of our property by building those magnificent places all round it, and in due course we hope to be in a position to tell you that we have realised that property to advantage and been able to pay off the mortgage thereon. The only other point I want to make on the accounts is to call your attention to the fact that in 1900—we always like to go 10 years back to view our progress—our subscriptions amounted to £5,126, and in 1910 they amounted to £11,314.

The CHAIRMAN: I have now formally to move that the Report of the Council as presented be received and adopted, and that it be printed in the *Journal* of the *Proceedings*.

Mr. J. F. C. SNELL: I have pleasure in seconding that.

The CHAIRMAN: I must ask if any members desire to make any observations or ask any questions with regard to the Report or Accounts.

A MEMBER: I should like to ask whether the investments put down at cost are worth more or less than the figure now.

Mr. R. HAMMOND: In the Report that has been laid before you you will notice that on page 833 it is stated that the investments in stocks and shares included in the assets appear in the accounts at cost price, with a book value of £3,133 2s. 10d., and their value at the current market prices on April 27, 1911, was £2,864.

Mr. R. A. CHATTOCK: I was interested to see on page 832 that the Institution proposes to hold informal meetings for the discussion of papers. I should like to ask if the papers to be submitted at those meetings are to be presented and printed beforehand, or to be simply in the nature of notes given at the time. It seems to me if they have to be printed beforehand, as the ordinary papers have, it will make rather too much of a business for what should necessarily be more of an informal discussion than anything else. At the Local Sections in Birmingham we have meetings of this kind, and find that they are very valuable, and the subjects are introduced without any paper; they are simply a few remarks made by one member, and a discussion is inaugurated upon them. I was wondering if these informal meetings were to be conducted on those lines, or were to be more formal in their nature.

The CHAIRMAN: I may say in answer to that question that nothing has been definitely settled with regard to the procedure at the informal meetings that are proposed. The matter will be very carefully gone into, and the Council will see what really seems best in the interest of the Institution.

The resolution was put and carried unanimously.

The CHAIRMAN: I now call upon the Honorary Treasurer to read the auditors' certificate of the accounts.

The HONORARY TREASURER read the auditors' certificate.

Mr. R. HAMMOND: I have pleasure in formally moving that the statement of accounts and balance sheet for 1910, of which copies were sent to the Members with the notice convening the meeting, be taken as read, and adopted.

Mr. J. F. C. SNELL: I have much pleasure in seconding that.

The resolution was put and carried unanimously.

Mr. SNELL: Mr. President and Gentlemen, I beg to move that the best thanks of the Institution be given to the Honorary Secretaries of the Local Sections, and the Local Honorary Secretaries and Treasurers abroad, for their kind services during the past year. When we know the amount of work which has been done by the Local Secretaries, and the important effect they have on the general well-being of the

Institution, I am sure you will accord your best thanks to these gentlemen.

Mr. L. GASTER: I have much pleasure in seconding this motion, and I speak very freely about the Secretaries' work. I know it is not an easy matter to get papers in time to be printed to produce a good discussion, and I am sure any one who has read the papers at the Sections can appreciate the work of the Local Secretaries. The least we could do is to thank them cordially, and wish them success for the next Session. I have much pleasure in seconding the resolution.

The resolution was put and carried unanimously.

Major W. A. J. O'MEARA: Mr. President and Gentlemen, I have great pleasure in moving formally that the best thanks of the Institution be given to Mr. Robert Hammond in recognition of the valuable services rendered by him as Honorary Treasurer of the Institution during the past Session. I think I am only expressing the feelings of the members of this Institution when I say that we feel very grateful indeed to Mr. Hammond for having undertaken the onerous duties of Honorary Treasurer. At all times the duties of such officer are anxious, but, as Mr. Hammond has reminded us, his duties during the past Session have been made more onerous still, because, instead of being a receiver of dividends, and being in the fortunate position of having a big balance, he has paid out our accumulated funds, and he is in the unenviable position of a borrower in respect of this magnificent building we are now occupying. I have great pleasure in moving the resolution.

Mr. S. SHARP: Mr. President and Gentlemen, in seconding the resolution moved by Major O'Meara, I endorse all that he has said with regard to the labours of Mr. Hammond. I should like to add one word. Mr. Hammond's mental activity, aided by that of the Finance Committee, has during the last two or three years altered the arrangement of the accounts, which perhaps has been observed, and again this year they have been rearranged with such success that I think they now stand in a form in which they never need be altered again. All the important accounts come first, and the minor accounts follow. I have much pleasure in seconding the resolution.

The resolution was put and carried unanimously.

Mr. R. HAMMOND: Mr. President and Gentlemen, I am not going to inflict another speech upon you, but I cannot permit these remarks to be made without saying how very grateful I am to you for your kind expression of appreciation. I must, however, disclaim the whole of the credit for the improvements which from time to time take place in the accounts. I think as a matter of fact some of these rearrangements came out of a suggestion of Mr. Sidney Sharp. He disclaims them, but it is by being helped by those who so ungrudgingly give their labour to the affairs of the Institution, like our Secretary, that one is able to bring these accounts forward in such a way as to be a credit to any Institution.

Mr. W. CLARK: Mr. President and Gentlemen, I have great

pleasure in formally moving that the best thanks of the Institution be accorded to the Honorory Auditors, Mr. Sidney Sharp and Mr. H. Alabaster, for their kind services during the past year. I am sure that we ought to be very grateful to them, although the matter evidently has been arranged amicably between them and the Honorary Treasurer, so that the accounts are presented in such a lucid manner. I am sure we cannot do better than give our best thanks for their services.

Mr. R. W. HUGHMAN: Mr. President and Gentlemen, I have pleasure in seconding this motion.

The resolution was put and carried unanimously.

The CHAIRMAN: I will call upon Mr. Sharp to reply.

Mr SIDNEY SHARP: I do not think it is the custom to reply to this resolution, but still I feel grateful to the mover and seconder and the other members for their appreciation of what Mr. Alabaster and myself have been able to do. We try to do our best, and I believe we meet with some success; at any rate, so long as we have the appreciation of the members, we are well rewarded.

Mr. CHATTOCK: Mr. President and Gentlemen, I have pleasure in moving that the best thanks of the Institution be tendered to Messrs. Bristows, Cooke and Carpmael for their kind services in the capacity of Honorary Solicitors to the Institution during the past year.

Mr. S. RENTELL: Mr. President and Gentlemen, I have much pleasure in seconding that proposal.

The resolution was put and carried unanimously.

The CHAIRMAN: I have to announce that the candidates whose names are on the balloting list have been duly elected. I also have to announce that no nominations having been received for election to the Council other than those announced at the Ordinary General Meeting on April 27th, 1911, the Council's nominees are, in accordance with Article 45 of the Articles of Association, duly elected to their respective offices. The following will therefore constitute the Council for the year 1911–12:—

President.

S. Z. DE FERRANTI.

Vice-Presidents.

W. DUDDELL, F.R.S.
MAJOR W. A. J. O'MEARA, C.M.G.
W. H. PATCHELL.
J. F. C. SNELL.

Members of Council.

W. W. COOK.
H. DICKINSON.
G. K. B. ELPHINSTONE.
J. S. HIGHFIELD.
H. HIRST.
B. M. JENKIN.
W. JUDD.
J. E. KINGSBURY.
P. V. MCMAHON.
R. K. MORCOM.
W. M. MORRISON.
S. L. PEARCE.
H. FARADAY PROCTOR.
C. P. SPARKS.
C. H. WORDINGHAM.

Associate Members of Council.

E. RUSSELL CLARKE. | S. MORSE.
H. E. WIMPERIS, M.A.

Honorary Treasurer.

ROBERT HAMMOND.

Honorary Auditors.

H. ALABASTER. | SIDNEY SHARP.

Mr. W. CLARK: Mr. President and Gentlemen, it is my extreme pleasure to propose that Mr. Sidney Sharp and Mr. H. Alabaster be elected honorary auditors for the year 1911–12.

Mr. HUGHMAN: I beg to second that.

The resolution was put and carried unanimously.

OBITUARY NOTICES.

PETER ALBERTINE was born in Switzerland in 1872, but spent most of his early life in the United States. In 1900 he returned to Switzerland, and was with Messrs. Sulzer Bros., of Winterthur, for five years. He was then appointed general manager of the London branch of the same firm. His death occurred on September 18th, 1910. He was elected a Member of the Institution in 1907.

THOMAS ANDREWS joined the first French Atlantic Telegraph Company in 1869, as superintendent of the station at Brest. In 1873 he was transferred to the Anglo-American Telegraph Company, and remained with them for twenty-seven years in the same capacity. When, in 1900, the French cable was abandoned, Mr. Andrews was sent to another station of the same Company at Havre, where he continued until his retirement in 1906. He became a Member of the Institution in 1873.

JAMES ROBERTSON BARR was born in 1885, and began his work as apprentice to Bruce, Peebles & Co., and was for a year at the Leith power station. He was afterwards designer to the Electric Construction Company, and took out some plant to erect in West Africa. In October, 1905, he was appointed assistant lecturer in electrical engineering at the Heriot Watt College. In 1908 he published a book on "Direct-current Engineering," and was following this with another on "Alternating-current Machinery" at the time of his death in December, 1910. He was elected an Associate Member of the Institution in 1906.

GUSTAV BINSWANGER-BYNG was born in 1855, and educated at Augsburg. At the age of 18 he came to London, and six years later commenced business at Peel Works, Manchester, as an electrical engineer. Later he became associated with Mr. Hugo Hirst in the General Electric Company, Manchester. He was chairman of the Manufacturers' Association of Great Britain, and a member of many other technical and public bodies. He was an advocate of Tariff Reform, and wrote a book on the subject which was frequently quoted by the leaders of the movement. He died on November 23,

1910, at Hampstead, at the age of 55. He became an Associate of the Institution in 1888, and was transferred to full Membership in 1891.

GEORGE EDWARD DERING was born in 1831, and educated at Rugby. In his early days he was one of the pioneers of telegraphy, and at his residence at Lockleys, near Welwyn, he conducted many experiments in this and other branches of science. He was interested in a process for the manufacture of steel rails, and in the discovery of suitable substances for insulators. His death occurred on February 17, 1911. He was elected a Member of the Institution in 1875.

S. S. DICKENSON died at New York on December 23, 1910. He was born at Plymouth in 1852, and entered the telegraph service in 1867. He was for ten years in the direct United States service at Torbay. In 1884 he joined the Commercial Cable Company, and established a station at Canso, of which he was superintendent for twenty years. In 1900 he established a cable station at the Azores, linking with Portugal and North America, for which he was decorated by the late King Carlos. In 1901 he established cable stations in the Philippine Islands. In 1904 he was appointed general superintendent of the Commercial Cable Company, afterwards becoming director and vice-president. He did much towards the perfecting of duplex working on cables. He was elected an Associate of the Institution in 1877, and was transferred to full Membership in 1889.

EUSTACE DOWN was born in 1885, and was trained in electrical engineering at the Northampton Institute, where, in 1903, he was awarded the diploma, having passed with distinction. He then went to Schenectady, and remained some years with the General Electric Company; and in 1906 became technical assistant and engineer to Messrs. W. R. Grace & Co., at Lima, and subsequently at Valparaiso. This position he held at the time of his death, which occurred on January 24, 1911.

BENJAMIN TRAILL FFINCH, C.I.E., died on October 22, 1910, at Blackheath, at the age of 70. He joined the Indian Telegraph Department in 1857, and had a large share in the development and extension of the telegraph service on its administration being taken over by the Government. In April, 1875, he was appointed Deputy-Director of the Indo-European Telegraph Department, and given charge of the Persian Gulf section. In 1893 he was made Director-Engineer of the same department, with headquarters at the India Office. He represented his department at Buda Pest in 1896, and received the decoration of C.I.E. in the following year. He retired from the service in 1902, and since 1904 was a director of Henley's Telegraph Works Company. He had been a Member of the Institution since 1872.

JAMES GRAVES died at Valentia, Ireland, on January 14, 1911. He was one of the oldest members of the telegraph service, having joined the Electric Telegraph Company in 1852. In 1861 he was appointed submarine electrician to the Company, in which capacity he took part in the laying of the Atlantic cables. He continued with the Atlantic Telegraph Company and their successors, the Anglo-American Telegraph Company, until June, 1909. He was altogether forty-five years at Valentia, and had been a Member of the Institution since 1873.

HENRY GRAHAM HARRIS was born in 1850, and was apprenticed at an early age to the Thames Ironworks Company. He was then with several engineering firms for short periods, and in 1874 became assistant to Sir Frederick Bramwell, being afterwards taken into partnership. His firm designed the electrical undertakings of the South Wales Electric Power Company and the Corporations of Ealing and Derby. Mr. Harris was frequently employed in arbitration cases, and at the time of his death was acting as arbitrator for the purchase of the National Telephone Company by the Post Office. He was elected a Member of the Institution in 1889. His death, after a short illness, occurred on October 12, 1910.

FREDERICK T. J. HAYNES entered the telegraph department of the Bristol and Exeter Railway in 1864, and in 1870 became telegraph superintendent. In 1876 he continued his duties with the Great Western Railway, who had taken the line over, and in 1888 he was made Divisional Telegraph Superintendent for the western section. He retired in 1901, and his death occurred on May 8, 1911. He was elected a Member of the Institution in 1872.

THOMAS GEORGE MACLEAR LADDS was trained at the School of Telegraphy, Hanover Square. In 1885 he entered the service of the Eastern Telegraph Company, at Gibraltar, being afterwards transferred to Alexandria. In 1896 he went to South Africa, and superintended the erection of plant for various gold-mining companies. He was afterwards for some time with the Eastern and South African Telegraph Company at Cape Town, and in 1903 was employed on electric signalling work with the Cape Government Railways, which position he held at the time of his death on January 30, 1911. He was elected an Associate Member in 1887, and was transferred to full Membership in 1898.

HENRY COOKE LEAKE died at Brighton on September 29, 1910, age 38. He was for many years head of the electrical department at Devonport Dockyard, and had recently been elected chief electrical engineer to the Chilian Navy. He joined the Institution as an Associate in 1895, and in 1899 was transferred to Associate Membership.

V. A. H. McCOWEN was born at Tralee in 1866, and educated in Dublin. He spent eight years at mechanical engineering, and afterwards two years at Finsbury Technical College under Professor Thompson. He then joined the staff of J. H. Gordon & Co., London, and was employed on several lighting schemes, being engineer in charge of the Sydenham undertaking. In 1892 he became engineer to the Killarney Electric Light Company, and in 1894 City Engineer of Belfast, where he superintended the original gas-engine scheme devised by Sir Alexander Kennedy. He was also for twelve years the City Council's consulting engineer. He received in 1907 the appointment of Borough Engineer of Salford, but a year or two later he was seized with paralysis, and was eventually compelled to leave his work. He died at Bath on September 8, 1910. He was elected an Associate Member of the Institution in 1890, and transferred to Membership in 1898.

JAMES HARDIE McLEAN was apprenticed at Belfast to Mr. Greenhill, later working on Mr. Ferranti's staff at Grosvenor Gallery and Deptford. He then went to take up a position with Messrs. W. Lucy & Co., of Oxford, and finally became general manager and engineer of the Midland Electric Corporation for Power Distribution, of Birmingham. He died on March 27, 1911. He joined the Institution in 1892, and was transferred to full Membership two years later.

BARON AUGUSTUS MANNERHEIM was born in 1875 and was trained at the Technical High School, Stockholm. On the completion of his course in 1893 he was with various firms in Stockholm and London, and with Messrs. Siemens and Halske, Berlin, and the Berliner Electrische Gesellschaft. In 1897 he was chief engineer to the Finnish Electrical Company, Helsingfors, and in 1899 chief engineer to the A. E. G., Berlin. In 1904 he received a similar appointment with the A. E. G. of South Africa at Johannesburg, and left in 1909 to take up private practice at Hoganäs, Sweden, which he continued up to the time of his death in June, 1911. He was elected an Associate Member of the Institution in 1905.

WILLIAM MIDDLETON was born in 1874 and was apprenticed to Messrs. Parsons, of Newcastle-on-Tyne, but at the age of 23 left them to go to the station of the Newcastle and District Lighting Company, of which he became assistant superintendent. He died on April 7, 1911, as the result of an accident. He was elected an Associate Member of the Institution in 1909.

JOHN EDWARD NEALE was born in 1870, and at the age of 23 went to India as assistant telegraph superintendent on the Great Indian Peninsula Railway. In 1898 he became telegraph super-

intendent, which position he held at the time of his death on May 25, 1911. He was one of the foremost telegraph engineers in India, and invented a voucher block instrument for single-line working which has been largely adopted on Indian railways. He joined the Institution in 1893, and was transferred to full Membership in 1897.

ALFRED LOVELL PHILLIPS was educated at Christ's Hospital and apprenticed to the Electrical Power Storage Company. After being employed by the Crystal Palace Supply Company and the Chelsea Electric Lighting Company, he joined the mains department of the Charing Cross Company in 1902. In 1910 he was employed by Messrs. Johnson and Phillips to put down lighting and power plant at Lobito, Portuguese West Africa, but while there he died on December 15, 1910. He joined the Institution in 1897 as Associate, and became an Associate Member two years later.

SIR JAMES CLIFTON ROBINSON died at New York on November 5, 1910. He was born at Birkenhead on January 1, 1848. He was tramway manager at Cork, at Bristol (1875–1882), and at Edinburgh (1882–1884). He travelled over the greater part of the world in connection with the construction of cable tramways. In 1892 he advised the electrification of the Bristol tramways, and carried out this and many other similar schemes. His best-known work was the conversion to electric working of the West London Tramways, under the name of the London United Tramways. He was elected an Associate Member of the Institution in 1894, and was transferred to full membership in 1908.

WILLIAM DUNLAP SARGENT was a native of Philadelphia, and served in the American Civil War under General Burnside. Subsequently he was with the Western Union Telegraph Company at Harrisburg and Chicago, and with the American District Telegraph at Philadelphia, where he installed the system. In 1876 he became general superintendent of the Bell Telephone Company, of Philadelphia, and was afterwards manager and vice-president of the New York and New Jersey Telephone Company, and director of the New York Telephone Company. He was joint designer of the lead-covered type of telephone cable, now in general use. He was elected a Foreign Member of the Institution in 1873, and was transferred to the class of Members in 1911. His death occurred on August 24, 1911.

GEORGE GLADMAN SARNEY was born in 1865 and was trained at the City and Guilds of London Institute. He was for two years with the British Electric Light Company, and was then employed with various firms for a number of years, mainly in lighting work. In this capacity he was placed in charge of lighting sections at several of the

exhibitions held at South Kensington during the eighties. In 1892 he was with the Electric Construction Corporation, London, and in 1900 became electrical assistant to Messrs. Williams and Couzens, of 39, Victoria Street, S.W., with whom he remained up to the time of his death, which occurred on June 7, 1911.

PERCY SEWELL SHEARDOWN received his early technical training under Professors Thompson and Perry at the City and Guilds Institute, where he gained first place with a medal in the final examination in 1894. He was then for a short time assistant at the power station at Bray, and was afterwards engaged on the electrification of the tramway from Dublin to Dalkey. He subsequently became chief electrical engineer to the Dublin United Tramways. His health recently broke down through overwork, and he died on June 19, 1911. He was a lecturer on engineering at Trinity College, Dublin, and became an Associate Member of the Institution in 1897, being transferred to full membership in 1904.

JACOB STÖTTNER was born in 1859 at Freising, Bavaria, and was apprenticed in 1875 to Messrs. Kayser, of Nuremberg. He subsequently worked under Messrs. Siemens and Halske, Mr. Hiram Maxim, Messrs. Siemens Bros. (Woolwich), and Messrs. Siemens-Schuckert, and in 1888 he became engineer and manager of the A. E. G. of Berlin, and was in charge of their exhibits at the World's Fair, Chicago, in 1893. Afterwards he was appointed manager of the Electrical Company, Ltd., the English agency for the A. E. G. Mr. Stöttner died on February 25, 1911. He was elected a Member of the Institution in 1895.

WILLIAM ISAAC TAYLOR was born in 1849 and apprenticed to Messrs. Losh, Wilson, & Bell, of Walker-on-Tyne, remaining with them as draughtsman, and later as assistant manager. In 1876 he went into partnership with Mr. A. Goodman, of Newcastle, as a consulting engineer. In 1878 he was appointed engineer and manager to the Barmoor Colliery, Lowick. He came to London in 1882 as manager and director for Messrs. Clarke, Chapman & Co., of Gateshead, and he was also for many years London representative of the Darlington Forge Company. He died on March 10, 1911. He was elected a Member of the Institution in 1904.

JOSEPH WETZLER was born at Hoboken, New Jersey, on December 6, 1863, and was educated at the Stevens Institute of Technology. In 1882 he entered the Weston Works at Newark, New Jersey, but his health failed and he was compelled to seek literary work. He was for a short time on the staff of the *Scientific American*, and then became editor of the *Electrical World* in association with Mr. T.

Commerford Martin. In 1890 he was offered, with Mr. Martin, the editorship of the *Electrical Engineer*, which he continued until 1898. He was joint author with Mr. Martin of "The Electric Motor and its Applications," and with him edited the electrical department of the new edition of Appleton's "American Cyclopædia of Applied Mechanics." He was a vice-president of the American Institute of Electrical Engineers, and was also president of the New York Electrical Society. In 1898 he organised the Electrical Engineer Institute of Correspondence Instruction, and came to London for the purpose of establishing the undertaking on a proper basis. He died on February 21, 1910. He became a Foreign Member of the Institution in 1901, and in 1904 was transferred to full Membership.

HARRY GEORGE YOUNG died at Edinburgh on March 29, at the age of 28. He was for several years with the National Electric Construction Company, Ltd., became superintendent of their power station at Musselburgh, and afterwards tramways assistant manager. Later he became engineer and manager of Bo'ness Electricity Works, which position he filled up to the time of his death. He was elected an Associate Member of the Institution in 1910.

The Institution of Electrical Engineers.

THE LIBRARY.

ACCESSIONS TO THE LIBRARY FROM JANUARY 1 TO JUNE 30, 1911.

All works are purchased unless otherwise stated.

IT IS PARTICULARLY DESIRABLE THAT MEMBERS SHOULD KINDLY PRESENT COPIES OF THEIR WORKS TO THE LIBRARY AS SOON AS POSSIBLE AFTER PUBLICATION.

Alexanderson, E. F. W. *See* Kennelly, A. E., and Alexanderson, E. F. W.

Allen, P. R. Internal-Combustion Engines at the Brussels Exposition. [Reprinted from *Cassier's Magazine*, Vol. 39.] 8vo. 54 pp. *London*, 1911

Presented by the Author.

American Journal of Science. Index to Vols. 21-30, 1906-1910. 8vo. *New Haven*, 1911

Arnold, E. Arbeiten aus dem Elektrotechnischen Institut der Grossherzoglichen Technischen Hochschule Fredericiana zu Karlsruhe. Hrsg. von E. Arnold. Vol 2, 1910-1911. 8vo. 358 pp. *Berlin*, 1911

Austin, L. W. *See* Robison, S. S. Manual of Wireless Telegraphy.

Ayrton, W. E. Biography of William Edward Ayrton, 1847-1908, by J. P[erry]. [Reprinted from the *Proceedings of the Royal Society*, Vol. 85.] 8vo. 8 pp. *London*, 1911

——— and **Mather, T.** Practical Electricity. A Laboratory and Lecture Course. 3rd ed. Revised and largely rewritten by T. Mather. 8vo. 562 pp. *London*, 1911

Presented by Professor T. Mather.

Baedeker, K. Die elektrischen Erscheinungen in metallischen Leitern. (Leitung, Thermoelektrizität, Galvanomagnetische Effekte, Optik.) 8vo. 154 pp. *Braunschweig*, 1911

Barton, E. H. A Text-book on Sound. 8vo. 703 pp. *London*, 1908

Presented by the Author.

Bauer, L. A. The Broader Aspects of Research in Terrestrial Magnetism. [Reprinted from *Science*, Vol 33, pp. 41–54.] 8vo. 15 pp. *Lancaster, Pa.*, 1911

Presented by the Author.

Belden, A. W., Delamater, G. R., Groves, J. W., and **Way, K. M.** Washing and Coking Tests of Coal. [*Bulletin of the Bureau of Mines*, No. 5.] 8vo. 62 pp. *Washington*, 1910

Presented by the Bureau of Mines.

Benischke, G. Die Schutzvorrichtungen der Starkstromtechnik gegen Atmosphärische Entladungen und Überspannungen. 2nd ed. [*Elektrotechnik in Einzeldarstellungen*, Heft 1.] 8vo. 131 pp. *Braunschweig*, 1911

Birks, L. *See* New Zealand. Reports of the Water Powers of.

Blanchin, P. *See* Zenneck, J. Précis de Télégraphie sans fil.

Bloch, L., and **Zaudy, R.** Elektrotechnische Winke für Architekten und Hausbesitzer. 8vo. 155 pp. *Berlin*, 1911

Blomefield, N. N. *See* Meares, J.W., and Blomefield, N. N.

Blondel, A. *See* Pacoret, A. La Technique de la Houille Blanche.

Board of Education. Report of the Departmental Committee on the Science Museum and the Geological Museum. Fol. 32 pp. *London*, 1911

Presented by the Board of Education.

Bohnenstengel, E. Elektrische Automaten und Fernschalter. 8vo. 155 pp. *Leipzig*, 1911

Bonazzi, O. Misura della permeabilitá del ferro nel campo magnetico delle scariche oscillatorie. 8vo. 24 pp. *Pisa*, 1910

Presented by the Author.

——— L'Induttanza per correnti alternate di un circuito comprendente ferro. [Reprinted from the *Rendiconti della R. Accademia dei Lincei*, Vol. 19, Ser. 5ª, 2º sem.] 8vo. 5 pp. *Roma*, 1910

Presented by the Author.

Borchers, W. *See* Jahrbuch der Elektrochemie.

——— Metallurgy, a brief outline of the Modern Processes for Extracting the more important Metals. Translated by W. T. Hall and C. R. Hayward. 8vo. 276 pp. *New York*, 1911

Breisig, F. Theoretische Telegraphie. [*Telegraphen und Fernsprech-Technik in Einzeldarstellungen.* Hrsg. von T. Karrass, Vol. 7.] 8vo. 446 pp. *Braunschweig*, 1910

Brew, W. Three-Phase Transmission. A Practical Treatise on the Economic Conditions Governing the Transmission of Electrical Energy by Underground and Overhead Conductors. 8vo. 186 pp. *London*, 1911

Presented by the Author.

British Westinghouse Electric and Manufacturing Company, Ltd. Electricity in Mines. Switchgear. 4to. 51 pp. *Manchester*, 1911

Presented by the Company.

Broadfoot, S. K. Motors, Secondary Batteries, Measuring Instruments and Switchgear. 8vo. 96 pp. *London*, 1911

Presented by the Author and Messrs. A. Constable & Co.

Bryant, J. M. *See* Swenson, B. V., Frankenfield, B., and Bryant, J. M.

Bureau of Standards, Washington. Announcement of the Change in the Value of the International Volt. [*Circular of the Bureau of Standards*, No. 29.] 8vo. 13 pp. *Washington*, 1910

Presented by the Bureau of Standards.

——— Fees for Testing Electrical and Photometric Standards and Electrical Measuring Instruments. [*Circular*, No. 6, 3rd ed.] 8vo. 22 pp. *Washington*, 1911

Carnegie Institution of Washington. *Department of Terrestrial Magnetism.* Annual Report of the Director, 1910. [Reprinted from the *Year Book* No. 9. pp. 195–204. 8vo. 10 pp. *Washington*, 1911

Presented by L. A. Bauer.

Castell-Evans, J. Physico-Chemical Tables. Vol. 2. Physical and Analytical Chemistry. 8vo. *London*, 1911

Chisholm, J. *See* Don, J., and Chisholm, J.

Cowles, W. S. *See* Robison, S. S. Manual of Wireless Telegraphy.

Crewe, H. T. The Practical Electrician's Pocket Book for 1911. 8vo. 364 pp *London*, 1911

Presented by Messrs. S. Rentell & Co., Ltd.

Crotch, A. The Elements of Telephony. 8vo. 94 pp. *London*, 1910

Presented by Messrs. E. and F. N. Spon, Ltd.

Cunningham, E. T. *See* Haller, G. F., and Cunningham, E. T.

Curtis, H. L. Mica Condensers as Standards of Capacity. [Reprinted from the *Bulletin of the Bureau of Standards*, Vol. 6, pp. 431–488]. 8vo. 58 pp. *Washington*, 1911

Presented by the Bureau of Standards.

Danneel, H. *See* Jahrbuch der Elektrochemie.

Delamater, G. R. *See* Belden, A. W., Delamater, G. R., and others.

Dellinger, J. H. *See* Wolff, F. A., and Dellinger, J. H.

——— The Temperature Coefficient of Resistance of Copper. [Reprinted from the *Bulletin of the Bureau of Standards*, Vol. 7, pp. 71–100]. 8vo. 30 pp. *Washington*, 1911

Presented by the Bureau of Standards.

Denis, P. J. Moteurs Électriques à Courant Continu et leurs Dispositifs de Commande. 8vo. 344 pp. *Paris*, 1911

Don, J., and **Chisholm, J.** Modern Methods of Water Purification. 8vo. 384 pp. *London*, 1911

Ebert, W., and **Nussbaum, J.** Hypochlorite und elektrische Bleiche. Praktisch-angewandter Teil. [*Monographien über angewandte Elektrochemie.* Hrsg von V. Engelhardt, Vol. 38.] 8vo. 379 pp. *Halle*, 1910

Ecker, Lazarus, and **Pettus, Sir John.** Fleta Minor. The Laws of Art and Nature in Knowing, Judging, Assaying, Fining, Refining and Enlarging the Bodies of Confined Metals. In two parts. The First contains Assays of Lazarus Ecker, now translated into English; the Second contains Essays on Metallick Words, as a Dictionary to many pleasing Discourses, by Sir John Pettus. Fol. 22 leaves, 345 pp., and 4 leaves, 133 pp. *London*, 1686

Edgcumbe, K. Whittaker's Electrical Engineer's Pocket Book. 3rd ed. 8vo. 605 pp. *London*, 1911

Presented by the Author.

Elliott Brothers. The Anschütz Gyro-Compass. Its History, Description, Theory, and Practical Use. 8vo. 111 pp. *London*, 1910

Presented by G. K. B. Elphinstone.

Engineering Standards Committee. Report on British Standard Thread Nuts and Bolt Heads for use in Automobile Construction. Fol. 10 pp. *London*, 1911

Presented by the Committee.

Epstein, J. Die magnetische Prüfung von Eisenblech. [Reprinted from *Elektrotechnische Zeitschrift*, Vol. 32.] 8vo. 22 pp. *Berlin*, 1911

Erskine-Murray, J. A Handbook of Wireless Telegraphy, its Theory and Practice. 3rd ed. 8vo. 402 pp. *London*, 1911

Presented by the Author and Messrs. Crosby, Lockwood & Son.

Evans, J. Castell-. *See* Castell-Evans, J.

Ewing, J. A. The Steam-Engine and other Heat-Engines. 3rd ed. 8vo. 621 pp. *Cambridge*, 1910

Presented by the Author and the Cambridge University Press.

Ferchland, P. Die elektrochemischen Patentschriften der vereinigten Staaten von Amerika. Auszüge aus den Patentschriften, Vol. 1. Elektrothermische Verfahren und Apparate; Entladungen durch Gase. [*Monographien über angewandte Elektrochemie*, Vol. 33. Hrsg. von V. Engelhardt.] 8vo. 210 pp. *Halle*, 1910

Fernald, R. H. Features of Producer-Gas Power-Plant Development in Europe. [*Bulletin of the Bureau of Mines*, No. 4.] 8vo. 227 pp. *Washington*, 1911

Presented by the Bureau of Mines.

Few, H. P. Calculations in Telegraphy and Telephony. 8vo. 97 pp. London, 1910

Presented by Messrs. S. Rentell & Co., Ltd.

Field, S. The Principles of Electro-Deposition. A Laboratory Guide to Electro-Plating. 8vo. 398 pp. *London*, 1911

Flaskamp. Tätigkeit der beiden Funkentelegraphen—Abteilungen in Südwest-afrika, 1904–1907. 8vo. 52 pp. *Berlin*, 1910

Fleming J. A. The Principles of Electric Wave Telegraphy and Telephony. 2nd ed. 8vo. 926 pp. *London*, 1911

Fowler, W. H. Electrical Engineers' Pocket Book, 1911. 11th ed. 8vo. 566 pp. *Manchester*, 1910

France. (*Ministère des Postes et des Télégraphes.*) Notices Descriptives sur quelques Installations Récentes du Service des Postes, Télégraphes et Téléphones. 4to. 280 pp. *Paris*, 1910

Presented by Major W. A. J. O'Meara.

——— (*Ministre des Postes et des Télégraphes.*) Distribution d'Énergie Électrique. Loi du 15 Juin 1906 et reglements Annexes. Décisions diverses rendues par le Ministre des Travaux Publics des Postes et des Télégraphes pour l'application de la loi et des règlements relatifs aux Distributions d'Énergie Électrique (15 Juin 1906—31 Decembre 1909.) 8vo. 348 pp. *Paris*, 1911

Frankenfield, B. *See* Swenson, B. V., Frankenfield, B., and Bryant, J. M.

Frazer, J. C. W. *See* Rice, G. S. The Explosibility of Coal Dust.

Frost, H. Good Engineering Literature. What to Read and How to Write, with suggestive information on allied topics. 8vo. 434 pp. *Chicago*, 1911

Gibson, A. H. Hydraulics and its Applications. 8vo. 773 pp. *London*, 1908

Giebe, E. Präzisionsmessungen an Selbstinduktionsnormalen. (Mitteilung aus der Physikalisch-Technischen Reichsanstalt.) [Reprinted from *Zeitschrift für Instrumentenkunde*, Vol. 31, pp. 6–20, and 33–52.] 8vo. 35 pp. *Berlin*, 1911

Grover, F. W. The Mutual Inductance of Two Parallel Coaxial Circles in terms of Hypergeometrical Series. [Reprinted from the *Bulletin of the Bureau of Standards*, Vol. 6, pp. 489–502.] 8vo. 14 pp. *Washington*, 1911
Presented by the Bureau of Standards.

Groves, J. W. *See* Belden, A. W., Delamater, G. R., and others.

Guérard, G. *See* Zenneck, J. Précis de Télégraphie sans fil.

Gumlich, E., and **Rogowski, W.** Die Messung der Permeabilität des Eisens bei sehr kleinen Feldstärken. ("Anfangspermeabilität.") (Mitteilung aus der Physikalisch-Technischen Reichsanstalt.) [Reprinted from *Annalen der Physik*, Vol. 34, pp. 235–257.] 8vo. 23 pp. *Leipzig*, 1911

Haanel, E. Recent Advances in the Construction of Electric Furnaces for the Production of Pig Iron, Steel, and Zinc. 8vo. 76 pp. *Ottawa*, 1910
Presented by the Author.

Haas, F. *See* Rice, G. S. The Explosibility of Coal Dust.

Habibur Rahman Khan. *See* Khan, H. R.

Hall, C. *See* Munroe, C. E., and Hall, C.

Hall, W. T., and **Hayward, C. R.** *See* Borchers, W. Metallurgy.

Haller, G. F., and **Cunningham, E. T.** The Tesla High Fequency Coil, its Construction and Uses. 8vo. 131 pp. *New York*, 1910

Hallwachs, W. *See* Kohlrausch, F. Gesammelte Abhandlungen.

Hancock, L. M. *See* New Zealand. Reports on the Water Powers of.

Hansen, L. Electric Light Power Plants of the East. Tables. 8vo. *Bangkok*, 1910
Presented by the Author.

Hausmann, E. *See* Sheldon, S., and Hausmann, E.

Hay, P. S. *See* New Zealand. Reports of the Water Powers of.

Hayward, C. R. *See* Borchers, W. Metallurgy.

Heydweiller, A. *See* Kohlrausch, F. Gesammelte Abhandlungen.

Hill, C. W Electric Crane Construction. 8vo. 333 pp. *London*, 1911
Presented by the Author.

Hiscox, G. D. Mechanical Appliances, Mechanical Movements and Novelties of Construction. 8vo. 396 pp. *London*, 1905

Hobart, H. M. A Dictionary of Electrical Engineering. Edited by H. M. Hobart. 2 vols. 8vo. *London*, 1910

Holcombe, A. M. Public Ownership of Telephones on the Continent of Europe. 8vo. 502 pp. *London*, 1911

Holmes, R. W. *See* New Zealand. Reports of the Water Powers of.

Home Office. Electricity in Mines Committee, 1909–1910. Report of the Departmental Committee appointed to consider the working of the existing Special Rules for the Use of Electricity in Mines. Fol. 45 pp. *London*, 1911

——— Minutes of Evidence before the Departmental Committee Appointed to consider the working of the existing Rules for the Use of Electricity in Mines. Fol. 220 pp. *London*, 1911

Horstmann, H. C., and **Tousley, V. H.** Electricians' Operating and Testing Manual. 8vo. 359 pp. *Chicago*, 1910

Hort, W. Technische Schwingungslehre. Einführung in die Untersuchung der für den Ingenieur wichtigsten periodischen Vorgänge aus der Mechanik starrer, elastischer, flüssiger und gasförmiger Körper, sowie aus der Elektrizitätslehre. 8vo. 234 pp. *Berlin*, 1910

Hutchinson, R. W. High Efficiency Electrical Illuminants and Illumination. 8vo. 285 pp. *New York*, 1911

Ibbetson, W. S. Practical Electrical Engineering for Elementary Students. 8vo. 167 pp. *London*, 1910

Presented by the Author.

International Electrotechnical Commission. British Electrotechnical Committee on Nomenclature. Terms commencing with the letters A to E in English and French. 8vo. 18 pp. *London*, 1910

International Telegraph and Telephone Conference, Paris, 1910. Comptes Rendus de la deuxieme Conférence Internationale des Techniciens des Administrations des Télégraphes et des Téléphones de l'Europe. 4to. 207 pp. *Paris*, 1910

Presented by Major W. A. J. O'Meara, C.M.G.

International Telegraph and Telephone Conference, Paris, 1910. Collection of Papers read, with discussions.

Première Question: Service Téléphonique Manuel ou Automatique.

Deuzième Question: (a) Standarisation des Circuits Téléphoniques; (b) Choix de la fréquence et Eventuellement à un courant Sinusoïdal, pour unifier les études Théoriques; (c) Conditions d'adaptation des Appareils Téléphoniques aux Lignes.

Troisième Question: Coexistence des Lignes à Courant Fort e à Courant faible.

Quatrième Question: La Téléphonie à grande distance; Construction des Câbles pour grand distance et des relais, combination des fils Aériens.

Cinquième Question: Procédés les plus nouveaux de conservation des Poteaux en bois par imbibition et constructions protectrices. Donneés pratiques y relatives.

Septieme Question: Systèmes Télégraphiques à Grand rendement. (Télégraphes machinaux multiplex et système Mercadier.)

6 vols. 4to. *Paris*, 1910

Presented by Major W. A. J. O'Meara, C.M.G.

(NOTE.—*There were not any Papers published to Question No.* 6.)

Iron and Steel Institute. Journal. Subject and Name. Index to Vols. 59–82, 1901–1910, and to Vols. 1–2 of the Carnegie Scholarship Memoirs, together with a historical note on the development of the Institute. Edited by G. C. Lloyd. 8vo. *London*, 1911

Presented by the Institute.

Jahrbuch der Elektrochemie. Berichten über die Fortschritte der Jähre 1894, u.s.w. Begrundet und bis 1901 herausgegeben von W. Nernst and W. Borchers. Herausgegeben von H. Danneel. 8vo. *Halle*, 1895, etc.

Presented by C. Weiss.

Johnson, J. H. Arc Lamps and Accessory Apparatus. 8vo. 132 pp. *London*, 1911

Presented by the Author and Messrs. A. Constable & Co.

Jones, A. G. *See* Shepard, W. M., and Jones, A. G.

Joseph, L. Industrial Finance, a Comparison between Home and Foreign Developments. (A Paper read before the National Electric Manufacturers' Association.) 8vo. *London*, 1911

Presented by the Frederick Printing Company, Ltd.

Joule, J. P. Introductory Research on the Induction of Magnetism by Electrical Currents. (1855.) [*Philosophical Transactions of the Royal Society*, 1856, pp. 287–296.] 4to. 10 pp. *London*, 1856

——— On the Fusion of Metals by Voltaic Electricity. [*Memoirs of the Literary and Philosophical Society of Manchester*, Vol. 14, pp. 49–52.] 8vo. 4 pp. *Manchester*, 1837

Presented by the Manchester School of Technology.

——— On some Thermo-dynamic Properties of Solids. (1858.) [*Philosophical Transactions of the Royal Society*, 1859, pp. 91–130.] 4to. 40 pp. *London*, 1859

——— New Determination of the Mechanical Equivalent of Heat. [*Philosophical Transactions of the Royal Society*, 1878, part 2, pp. 365–383.] 4to. 19 pp. *London*, 1878

Presented by the Manchester School of Technology.

Jude, R. H., and **Satterly, J.** Matriculation Magnetism and Electricity. 8vo. 422 pp. *London*, 1910

Kammerhof, M. Der Edisonakkumulator. Seine technischen und wirtschaftlichen Vorteile gegenüber der Bleizelle. 8vo. 187 pp. *Berlin*, 1910

Karapetoff, V. Experimental Electrical Engineering and Manual for Electrical Testing. 2nd ed. 2 vols. 8vo. *New York*, 1910–1911

Karrass, T. *See* Breisig, F. Theoretische Telegraphie.
See Knopf, G. Stromversorgung der Telegraphen und Fernsprechanstalten.
See Winnig, K. Die Bautechnik für Oberirdische Telegraphlinien.

Kelvin, Lord. Mathematical and Physical Papers, Vol. 5. *See* Thomson, William, Baron Kelvin.

Kempe, H. R. The Engineers' Year-Book of Engineering Formulæ, Rules, Tables, Data, and Memoranda for 1911. 18th ed. 8vo. 1356 pp. *London*, 1911

Presented by the Author and Messrs. F. C. and W. H. Smith.

Kennelly, A. E. Graphic Representations of the Linear Electrostatic Capacity between Equal Parallel Wires. [Reprinted from the *Electrical World*, Vol. 56.] 8vo. 3 pp. *New York*, 1910

——— On the modifications in Hering's Laws of Furnace Electrodes introduced by including Variations in Electric and Thermal Resistivity. (A Paper read before the American Institute of Electrical Engineers). 8vo. 17 pp. *New York*, 1910

Presented by the Author.

——— Telegraph-Cable Repairing on a Christmas Day. [Reprinted from *Popular Electricity*, Vol. 2, pp. 779–782]. 8vo. 4 pp. *New York*, 1910

Kennelly, A. E. (CONTINUED). Vector-Diagrams of Oscillating-Current Circuits. [From the *Proceedings of the American Academy of Arts and Sciences*, Vol. 46, pp. 373–421.] 8vo. 49 pp. *New York*, 1911
Presented by the Author.

——— Vector Power in Alternating Circuits. (A paper read before the American Institute of Electrical Engineers.) 8vo. 35 pp. *New York*, 1910

——— and **Alexanderson, E. F. W.** The Physiological Tolerance of Alternating-Current Strengths up to Frequencies of 100,000 cycles per second. [Reprinted from the *Electrical World*, Vol. 56.] 8vo. 7 pp. *New York*, 1910
Presented by A. E. Kennelly.

Khan, H. R. Water Wireless Telegraphy. 8vo. 39 pp. *Allahabad*, 1911
Presented by the Author.

Knoft, G. Die Stromversorgung der Telegraphen- und Fernsprechanstalten. [*Telegraphen und Fernsprech-Technik in Einzeldarstellungen*, Hrsg. von T. Karrass, Vol. 9.] 8vo. 255 pp. *Braunschweig*, 1910

Kohlrausch, F. Gesammelte Abhandlungen von Friedrich Kohlrausch. Herausgegeben von W. Hallwachs, A. Heydweiller, K. Strecker, und O. Wiener, Vol. 1. Elastizität, Wärme, Optik. absolute elektrische Messungen und Verschiedenes. 8vo. *Leipzig*, 1910

Kön. Materialprüfungsamt der technischen Hochschule zu Berlin. Bericht über die Tätigkeit des Amtes im Betriebsjahr 1909. [*Mitteilungen aus dem Kön. Materialprüfungsamt zu Gross Lichterfelde West*, Vol. 28, pp. 357–468.] 8vo. 112 pp. *Berlin*, 1910

Kraus, F., and **Nicolai, G.** Das Elektrokardiogramm des gesunden und kranken Menschen. 8vo. 344 pp. *Leipzig*, 1910

Kreisinger, H. *See* Randall, D. T., and Kreisinger, H.

Larmor, Sir J. *See* Thomson, William, *Baron Kelvin.*

Larsen, A. Rice, G. S. The Explosibility of Coal Dust.

Laue, M. Das Relativitätsprinzip. 8vo. 218 pp. *Braunschweig*, 1911
Presented by Messrs. F. Vieweg and Sohn.

Le Bon, G. The Evolution of Forces. Edited by F. Legge. 8vo. 403 pp. *London*, 1908

Legge, F. *See* Le Bon, G. Evolution of Forces.

Ley, H. Die Beziehungen zwischen Farbe und Konstitution bei organischen Verbindungen. 8vo. 254 pp. *Leipzig*, 1911
Presented by S. Hirzel.

Lindeck, S. Über eine Beziehung zwischen dem Temperaturkœffizienten und dem spezifischen Widerstand einiger Metalle, insbesondere von Kupfer. (Mitteilung aus der Physikalisch-Technischen Reichsanstalt.) [Reprinted from the *Verhandlungen der Deutschen Physikalischen Gesellschaft*, Vol. 13, pp. 65–71.] 8vo. 7 pp. *Braunschweig*, 1911

Lüdtke, H. Beiträge zur Behandlung der elektromagnetischen Lichttheorie und der Lehre von den elektrischen Schwingungen. Nebst einem Anhang von den Geschwindigkeit der Elektrizität. [Reprinted from *Zeitschrift für den physikalischen und Chemischen Unterricht*, Vol. 2.] 8vo. 120 pp. *Berlin*, 1911

Lydall, F. *See* Wilson, E., and Lydall, F.

Marconi International Marine Communication Company, Ltd. Marconi Telegraphy. A short History of its Invention, Evolution and Commercial Development. 8vo. 92 pp. *London n.d.*

Mather, T. *See* Ayrton, W. E., and Mather, T.

Maycock, W. P. Electric Wiring Diagrams. A Collection, with brief explanations, of most of the Diagrams given in the same Author's work, "Electric Wiring, Fittings, Switches, and Lamps." 8vo. 146 pp. *London*, 1911

Presented by the Author.

———— Electric Wiring, Fittings, Switches, and Lamps. Circuits. 4th ed. 8vo. 638 pp. *London*, 1911

Presented by the Author.

Meares, J. W., and **Blomefield, N. N.** The Law Relating to Electrical Energy in India, being the Indian Electricity Act, 1910, with a General Introduction, Notes on Clauses and Appendices consisting of Rules, Model Forms, etc. 8vo. 439 pp. *Calcutta*, 1910

Presented by J. W. Meares.

"Mechanical World." Electrical Pocket Book for 1911, containing a Collection of Electrical Engineering Notes, Rules, Tables and Data. 8vo. 208 pp. *Manchester*, 1911

Mogg, G. *See* Pratt, A. G., and Mogg, G.

Moldenke, R. The Coke Industry of the United States as related to the Foundry. [*Bulletin of the Bureau of Mines*, No. 3.] 8vo. 32 pp. *Washington*, 1910

Presented by the Bureau of Mines.

Morgan, A. P. Wireless Telegraph Construction for Amateurs. 8vo. 200 pp. *New York*, 1910

Müller, A. Das Problem des absoluten Raumes und seine Beziehung zum allgemeinen Raumproblem. 8vo. 164 pp. *Braunschweig*, 1911

Presented by Messrs. F. Vieweg and Sohn.

Munroe, C. E., and **Hall, C.** A Primer on Explosives for Coal Miners. [*Bulletin of the U.S. Geological Survey*, No. 423.] 8vo. 61 pp. *Washington*, 1909

Presented by the Bureau of Mines.

Nernst, W., and **Borchers, W.** *See* Jahrbuch der Elektrochemie.

Newcastle and Gateshead Incorporated Chamber of Commerce. Year Book and Commercial Review, 1911. Edited by H. Shaw. 8vo. *Newcastle*, 1911

New Zealand. Reports on the Water-Powers, etc., of New Zealand by L. M. Hancock, P. S. Hay, L. Birks, and R. W. Holmes. Fol. *Wellington, N.Z.*, 1904–1910

Presented by L. Birks.

Nicolai, G. *See* Kraus, F., and Nicolai, G.

Nussbaum, J. *See* Ebert, W., and Nussbaum, J.

O'Conner, H. Gas Manufacture and Lighting. (Royal Scottish Society of Arts Keith Lecture, 1909.) 8vo. 118 pp. *London*, 1910

Presented by the Royal Scottish Society of Arts.

Orlich, E. Über eine Kompensation der Kapazität in grossen Widerständen. (Mitteilung der Physikalisch-Technischen Reichsanstalt.) [Reprinted from the *Verhandlungen der Deutschen Physikalischen Gesellschaft*, Vol. 12, pp. 949–954.] 8vo. 6 pp. *Braunschweig*, 1910

Ovitz, F. K. *See* Porter, H. C., and Ovitz, F. K.

Pacific Gas and Electric Company. Properties Owned and Operated, Territory Served, Finances, History, and Statistics. Oblong 8vo. 268 pp. *California*, 1911

Presented by the Company.

Pacoret, E. La Technique de la Houille Blanche et des Transports d'Énergie Électrique, Vol. 1. Creation et Aménagement des Chutes d'Eau, Vol. 2. Utilisation de l'Énergie des Chutes d'Eau. Prèface de A. Blondel. 2 vols. 8vo. *Paris*, 1911

Pecheux, H. Les Lampes Electriques. 8vo. 186 pp. *Paris*, 1911

Pedersen, P. O. Resonanz in gekoppelten Schwingungskreisen. [Reprinted from *Jahrbuch der drahtlosen Telegraphie*, Vol. 4, pp. 449–459.] 8vo. 11 pp. *Leipzig*, 1911

——— Wirbelstromverluste in und effektiver Widerstand von geraden, runden Metallzylindern. [Reprinted from *Jahrbuch der drahtlosen Telegraphie*, Vol 4, pp. 501–515.] 8vo. 15 pp. *Leipzig*, 1911

——— Drahtlose Schnelltelegraphie. [Reprinted from *Jahrbuch der drahtlosen Telegraphie*, Vol. 4, pp. 524–531.] 8 pp. *Leipzig*, 1911

Presented by the Author.

Peel-Conner Telephone Works, Ltd. Post Office Glasgow Telephone Service. 4to. 8 pp. *London*, 1910

Presented by the Peel-Conner Telephone Works, Ltd.

Pender, H. Principles of Electrical Engineering. 8vo. 351 pp. *New York*, 1910

P[erry], J. *See* Ayrton, W. E. Biography.

Petersen, W. Hochspannungstechnik. 8vo. 336 pp. *Stuttgart*, 1911

Pettus, Sir J. *See* Ecker, L., and Pettus, Sir J.

Phœnix Assurance Company, Ltd. The Phœnix Fire Office Rules for the Erection of Lightning Conductors. 8vo. 8 pp. *London*, 1910

Presented by the Phœnix Assurance Company, Ltd.

——— The Phœnix Fire Office Rules for Electric Light and Power Installations and Telephone, Heating Installations, etc. 39th ed. (2nd issue). 8vo. 38 pp. *London*, 1911

Presented by the Phœnix Assurance Company, Ltd.

Picot, E. *See* Zenneck, J. Précis de Télégraphie sans fil.

Porter, H. C., and **Ovitz, F. K.** The Volatile Matter of Coal. [*Bulletin of the Bureau of Mines*, No. 1.] 8vo. 56 pp. *Washington*, 1910.

Presented by the Bureau of Mines.

Pratt, A. G., and **Mogg, G.** Notes on Telegraphy. A simple exposition of the Rudiments of Technical Telegraphy and Telephony. 2nd. ed. 8vo. 231 pp. *London*, 1910

Presented by the Authors.

Randall, D. T., and **Kreisinger, H.** North Dakota Lignite as a Fuel for Power-Plant Boilers. [*Bulletin of the Bureau of Mines*, No. 2.] 8vo. 42 pp. *Washington*, 1910
Presented by the Bureau of Mines.

Rentell, S., & Co., Ltd. The Telegraphist's and Telephonist's Note Book. 8vo. 133 pp. *London, n.d.*
Presented by the Author.

Rice, G. S. The Explosibility of Coal Dust. With Chapters by J. C. W. Frazer, A. Larsen, F. Haas, and C. Scholz. [*Bulletin of the U.S. Geographical Survey*, No. 425.] 8vo. 186 pp *Washington*, 1910
Presented by the Bureau of Mines.

Richardson, A. The Evolution of the Parsons Steam Turbine. 4to. 282 pp. *London*, 1911
Presented by Messrs. C. A. Parsons & Co.

Robertson, D. The Mathematical Design of Transformers. (Being an excerpt from a Treatise on "Transformers" by H. Bohle and D. Robertson, pp. 164–282.) 8vo. 121 pp. *London*, 1910
Presented by the Author.

Robison, S. S. Manual of Wireless Telegraphy for the use of Naval Electricians. With revisions and the additions of Chapters III., IV., and V., by L. W. Austin and W. S. Coles. 8vo. 129 pp. *Annapolis, Md.*, 1909

Rodenhauser, W., and **Schoenawa, I.** Elektrische Öfen in der Eisenindustrie. 8vo. 339 pp. *Leipzig*, 1911

Rogowski, W. *See* Gumlich, E., and Rogowski, W.

——— Zur Streuung des Drehstrommotors. (Mitteilung aus der Physikalisch-Technischen Reichsanstalt.) [Reprinted from *Elektrotechnische Zeitschrift*, Vol. 31.] 8vo. 14 pp. *Berlin*, 1910

Rosa, E. B. Photometric Units and Nomenclature. [Reprinted from the *Bulletin of the Bureau of Standards*, Vol. 6. pp. 543–572.] 8vo. 30 pp. *Washington*, 1911
Presented by the Bureau of Standards.

Sartori, G. Macchine a corrente alternata a collettore. [Estratto dal "*Il Monitore Tecnico*."] 8vo. 61 pp. *Milano*, 1911
Presented by the Author.

Satterly, J. *See* Jude, R. H., and Satterly, J.

Schneider, N. H. Low-Voltage Electric Lighting with the Storage Battery. 8vo. 94 pp. *London*, 1911
Presented by Messrs. E. & F. N. Spon, Ltd.

——— Wiring Houses for the Electric Light, with special reference to Low-Voltage Battery Systems. 8vo. 94 pp. *London*, 1911
Presented by Messrs. E. & F. N. Spon, Ltd.

Schoenawa, I. *See* Rodenhauser, W., and Schoenawa, I.

Scholz, C. *See* Rice, G. S. The Explosibility of Coal Dust.

Schon, H. A. E. C. Hydro-Electric Practice. A Practical Manual of the Development of Water Power, its Conversion to Electric Energy, and its Distant Transmission. 8vo. 397 pp. *Philadelphia*, 1908

Schon, H. A. E. C. The same. 2nd ed. 8vo. 400 pp. *Philadelphia*, 1911
Presented by Messrs. J. B. Lippincott Company.

Schweizerische Elektrotechnische Verein. Statistik uber Starkstromanlagen. Allgemeiner Teil. Zentralanlagen Kategorie A (eigentliche Elektrizitätswerke mit Stromlieferung an Dritte) pro 1909. Bearbeitet vom Generalsekretariat des S.E.V. Fol. *Zurich*, 1910
Presented by the Schweizerische Elektrotechnische Verein.

Sheldon, S., and **Hausmann, E.** Dynamo-Electric Machinery; its Construction, Design, and Operation. Direct-Current Machines. 8th ed. 8vo. 337 pp. *New York*, 1910

Shepard, W. M., and **Jones, A. G.** The Watthour Meter. 8vo. 190 pp. *San Francisco*, 1910

Signorel, J. L'Électrification des Grandes Lignes de Chemins de Fer. 8vo. 263 pp. *Paris*, 1911

Simon, H. T. Der elektrische Lichtbogen (Experimentalvortrag). 8vo. 52 pp. *Leipzig*, 1911

Spon, E., and **F. N., Ltd.** Spons' Architects' and Builders' Pocket Book for 1911. Edited by C. Young and S. M. Brooks. 2 Vols. 8vo. *London*, 1911
Presented by Messrs. E. & F. N. Spon, Ltd.

Standard Third Rail Company. W-S Standard Under-running Third Rail. 8vo. 24 pp. *New York*, 1911
Presented by the Authors.

Steinmetz, C. P. Engineering Mathematics. A Series of Lectures delivered at Union College. 8vo. 309 pp. *New York*, 1911

Stille, C. Telegraphen- und Fernsprechkabel-anlagen. 8vo. 366 pp. *Braunschweig*, 1911

Strecker, K. *See* Kohlrausch, F. Gesammelte Abhandlungen.

Swenson, B. V., Frankenfield, B., and **Bryant, J. M.** The Testing of Electro-Magnetic Machinery and other Apparatus. Vol. II. Alternating Currents. 8vo. 350 pp. *New York*, 1911
Presented by Messrs. Macmillan & Co., Ltd.

Taylor, A. J. Wallis-. *See* Wallis-Taylor, A. J.

Testorf, F. Die Elektrizität als Antriebskraft für Zeitmessinstrumente. [*Fachbibliothek für Uhrmacher*, Band II.] 8vo. 215 pp. *Halle*, 1910

Thomson, William, *Baron Kelvin.* Mathematical and Physical Papers, Vol. 5. Thermodynamics, Cosmical and Geological Physics, Molecular and Crystalline Theory, Electro-dynamics. Arranged and revised, with brief annotations by Sir J. Larmor. 8vo. 618 pp. *Cambridge*, 1911
Presented by Lady Kelvin and Sir J. Larmor.

——— His way of Teaching Natural Philosophy. By D. Wilson. 8vo. *Glasgow*, 1910
Presented by Messrs. John Smith & Son, Ltd.

Timbie, W. H. Elements of Electricity for Technical Students. 8vo. 567 pp. *New York*, 1911

Tousley, V. H. *See* Horstmann, H. C., and Tousley, V. H.

Turchini, S. *See* Zimmern, A., and Turchini, S.

Valbreuze, R. de. Notions Générales sur la Télégraphie sans fil et la Téléphonie sans fil. 4th ed. 8vo. 487 pp. *Paris*, 1910

Viallefond, H. La Contribution des Patentes des Usines d'Électricité. 8vo. 78 pp. *Paris*, 1911

Vicarey, R. W. The Treatment of Storage Batteries. 8vo. 69 pp. *London*, 1907

Presented by Messrs. S. Rentell & Co., Ltd.

Vigneron, E. Induction et Courants Alternatifs. [*Encyclopédie Électrotechnique*, Fasc. 5.] 8vo. 147 pp. *Paris*, 1910

Vigneron H. Électrochimie et Électrométallurgie. 8vo. 296 pp. *Paris*, 1911.

Wallis-Taylor, A. J. Aerial Wire Rope-Ways. Their Construction and Management. 8vo. 254 pp. *London*, 1911

Walmsley, R. M. Electricity in the Service of Man. A Popular and Practical Treatise on the Applications of Electricity to Modern Life. Vol. I. The History and Principles of Electrical Science. 8vo. *London*, 1911

Presented by the Author and Messrs. Cassell & Co., Ltd.

Warr, J. W. The Electrical Ignition of Petrol Engines. 8vo. 82 pp. *London*, 1910

Presented by the Author.

Way, K. M. *See* Belden, A. W., Delamater, G. R., and others.

Webb, H. L. The Development of the Telephone in Europe. With an Introduction by H. Cox. (Being a reprint of Articles from *Electrical Industries*, 1910.) 8vo. 78 pp. *London*, 1911

Presented by the Author and the Publisher.

Weber, W. L. Handy Electrical Dictionary. 8vo. 224 pp. *London*, 1902

Presented by Messrs. S. Rentell & Co., Ltd.

Whittaker's Electricai Engineers Pocket-Book. *See* Edgcumbe, K.

Wiener, O. *See* Kohlrausch, F., Gesammelte Abhandlungen.

Wilson, D. *See* Thomson, William, *Baron Kelvin*.

Wilson, E., and Lydall, F. Electrical Traction. Vol. 1. Direct Current. Vol. 2. Alternating Current. 2 vols. 8vo. *London*, 1907

Winnig, K. Die Grundlagen der Bautechnik für Oberirdische Telegraphenlinien. [*Telegraphen- und Fernsprech-Technik in Einzeldarstellungen*, Hrsg. von. T. Karrass, vol. 8.] 8vo. 326 pp. *Braunschweig*, 1910

Wolff, F. A., and **Dellinger, J. H.** The Electrical Conductivity of Copper. [Reprinted from the *Bulletin of the Bureau of Standards*, Vol. 7, pp. 103–126.] 8vo. 14 pp. *Washington*, 1911

Presented by the Bureau of Standards.

Wright J. Electric Furnaces and their Industrial Applications. 2nd ed. 8vo. 332 pp. *London*, 1910

Young, C., and **Brooks, S. M.** *See* Spon, E. & F. N., Ltd. Architects' and Builders' Price Book.

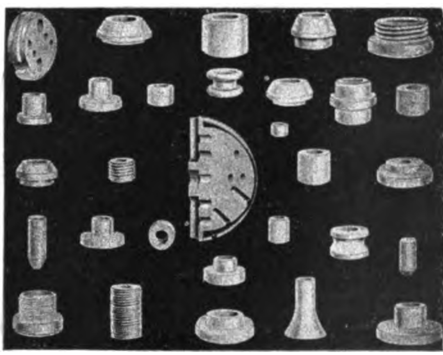
Zaudy, R. *See* Bloch, L., and Zaudy, R.

Zenneck, J. Précis de Télégraphie sans fil; complement de l'Ouvrage "Les Oscillations Électromagnetiques et la Télégraphie sans fil." Traduit de l'Allemand par P. Blanchin, G. Guérard et E. Picot. 8vo. 392 pp. *Paris*, 1911

——— Die Verwertung des Luftstickstoffs mit Hilfe des elektrischen Flammenbogens (Vortrag gehalten am 23 Sept. 1910 auf der 82 Versammlung Deutscher Naturforscher und Ärzte in Königsberg.) 8vo. 29 pp. *Leipzig*, 1911

Presented by S. Hirzel.

Zimmern, A., and **Turchini, S.** Les Courants de Haute Fréquence et la d'Arsonvalisation. 8vo. 96 pp. *Paris*, 1910



BUYERS' GUIDE.

Being a Classified Index of Names, Addresses, and Specialities of Firms Advertising in this Journal.

(Where no folio is given Advertisement does not appear in this Issue.)